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Advanced Aquarist's Online Magazine

Granular Activated Carbon, Part 2
West Atlantic Corals, Part 2
Macroalgaes
Light Measurement Tips

photographs by Jake Adams

Cover Photo

Siderastrea siderea (left), *Diploria labyrinthiformis* (middle), *Montastrea annularis* (right) and *Diploria strigosa* (bottom center). Inset: *Manicina sp.* Photos by Aldo Croquer and Jake Adams.

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ADVANCED AQUARIST'S ONLINE MAGAZINE

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EDITORIAL

FEBRUARY 2008

By Terry Siegel

I've often been asked what is a science, or what is the scientific method?

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Keywords (AdvancedAquarist.com Search Enabled): Editorial, Terry Siegel
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Our February issue this year is particularly heavy in content - something we are proud of. What is especially important to us is the high level of scientific investigation we are providing our readers with. *Advanced Aquarist* has always tried to offer as much material as available to us that is experimentally and therefore factually based. Toward this end we are very grateful to researches like Dana Riddle, Sanjay Joshi, Jake Adams, and now Ken Feldman and his colleagues. What is especially true of the work done by these scientists is that most of it is experimentally based, not simply a synopsis of someone else's work.

I've often been asked what is a science, or what is the scientific method? To this question I sometimes reply, 'it is the disinterested pursuit of the truth.' The critical word here is 'disinterested.' But, what does that mean? For one thing it means that the conclusion, truth or theory reached is not ideally influenced by whether it makes us happy or sad, whether we like it or not. In fact, it is the goal of the scientific researcher to eliminate him or herself from the experiment. A scientist doesn't begin with a belief, privatively held or supernaturally ordained. A researcher begins with a collection of observable and or measurable phenomena. The researcher than develops a hypothesis about this phenomena, which is then subjected to experimentation to determine whether the hypothesis or conclusion regarding this specific collection of phenomena is repeatable. For example, if one adds chemical A to chemical B, and there are no other conditions or variables introduced, it results in the formation of chemical C. And, every time this mixture is undertaken C is produced - this is called in scientific circles, repeatability. Furthermore, it doesn't matter whether the experimenter or anyone else for that matter likes or dislikes what is then called a theory. Usually, scientists will then share their theories, so that other researchers can retest these conclusions or theories.

The philosophical terminology the scientific method uses is called induction (aposteriori reasoning), as opposed to deduction (apriori reasoning). The dictionary defines aposteriori as, *1. from particular instances to a general principle or law; based upon actual observation or upon experimental data: a posteriori argument that derives the theory from the evidence.* Similarly, the dictionary defines apriori reasoning as, *1. from a general law to a particular instance; valid independently of observation. 2. existing in the mind prior to and independent of experience, as a faculty or character trait. Cf. a posteriori (def. 2) 3. not based on prior study or examination; nonanalytic: an a priori judgment.* Religious belief uses deductive reasoning, whereas, science employs inductive reasoning - astrology (deductive) compared to astronomy (inductive) for example. Without science it is very unlikely that we could send a space ship to the moon, and for that matter have successful reef tanks.

The left and right sides of Terry's tank.

FEATURE ARTICLE

Granular Activated Carbon, Part 2: Modeling of Operational Parameters for Dissolved Organic Carbon Removal from Marine Aquaria

By Ken S. Feldman, Lauren F. Vernese, Karl T. Mueller, Kelly Maers

Chemistry Department, The Pennsylvania State University. In Part 2, the authors will discuss the results of their research and make some recommendations to the aquarist on its usage.

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Results and Discussion

Using the Langmuir Isotherm Model to Calculate the Total Binding Capacity of Hydrocarbon2 (HC2)

Solutions of basic blue 3 dye (BB3) and, independently, fluorescein disodium (FL) in 35 ppt salinity salt water were prepared by adding 30 mg of dye to 1.20 L of salt water (from Instant Ocean salt mix and distilled water, 77 ^{o}F). 100.0 mL portions of each dye solution were placed in 250 mL flasks, and so each flask initially contained 2.5 mg of dye and the overall dye concentration was 25 mg/L. A carefully weighed amount of HC2 was added to each flask. The amounts added ranged between 10 mg and 100 mg as indicated in Table 1. Each flask was tightly stoppered and clamped onto a shaker apparatus that continuously agitated the flasks to ensure good contact between the solution and the HC2 sample. The dye concentration in each flask was assayed every 3 - 5 days by spectrophotometric measurement using a Beckman DU70 Spectrophotometer. The BB3 sample dye concentrations were measured at 645 nm, and the fluorescein solutions were recorded at 490 nm (nm = nanometer, a measure of spectral wavelength). The experiment was continued until sequential measurements did not exhibit much change in the amount of dye present (i.e. the HC2 was saturated and could not absorb any more dye). This criterion was met in the BB3 run at 17 days, whereas the fluorescein samples reached equilibrium after 14 days. The experimentally measured dye absorptions are given in Table 1. The key Langmuir model parameters 1/x and 1/C (Eq. (5)) can be derived from these experimental quantities (Table 1). 1/C is just the inverse of the dye concentration at the end of the experiment (= equilibrium), and this dye concentration can be derived by simply multiplying the initial dye concentration (= 25 mg/L) by the ratio A_{eq}/A_o, where A_{eq} and A_o are the dye absorptions of the solution at the end of the experiment and at the beginning, respectively. The quantity 1/x is calculated by dividing the amount of HC2 used by the amount of dye absorbed (= (2.5 mg)(1-A_{eq}/A_o)). Graphing 1/c vs. 1/x then gives the desired quantity, the binding capacity (x_m) of HC2 for these dyes, as the inverse of the Y-intercept. By this analysis, HC2's binding capacity for BB3 in seawater is 61 ± 7 mg/gm, and for fluorescein is 45 ± 2 mg/gm. Note that the Y-intercept values from Figure 3 are reported in units of mg of HC2/mg of dye, so the derived x_m value was multiplied by 0.001 to arrive at the mg of dye/gm of HC2 values noted above. For subsequent analyses, it will become convenient to just average these values to derive a "general" binding capacity for dyes by HC2; $x_{m(ave)}$ ~ 53 mg/gm.

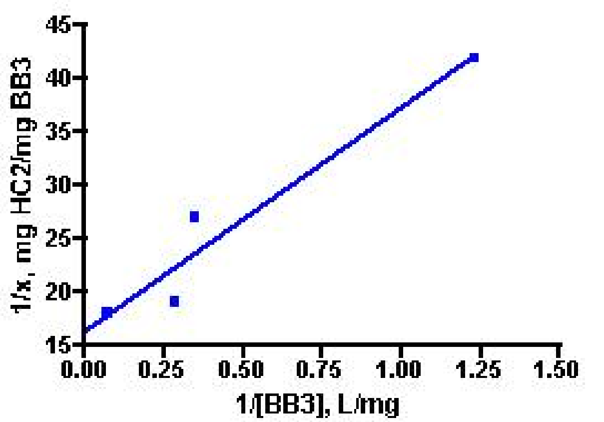
Table 1. Experimental data and derived quantities for the Langmuir isotherm-based calculation of the binding capacity of HC2.

HC2 (mg)	A_o	A_{eq}	1/C (L/mg)	1/x (mg HC2/mg dye absorbed)
0	2.77			
20.1		1.56	0.071	18
39.8		0.39	0.28	19
60.1		0.32	0.35	27
100.4		0.090	1.20	42
0	2.30			
10.4		1.90	0.048	24
41.3		0.98	0.094	29
100.7		0.24	0.38	45

Rate of Dye Removal as a Function of HC2 Amount

The first series of dye removal experiments utilized constant amounts of both BB3 and fluorescein, and the amount of GAC was varied. We expected that the calculated k values would be invariant with respect to the amount of GAC used (see the discussion associated with Eq. (3)), and so these experiments will provide a good test of our model and its assumptions. The experimental set-up is simple, and follows one used by other authors. A five-gallon bucket with a small aperture in the top was filled with

4.0 gallons of freshly prepared 35 ppt salinity salt water, and 243 mg of basic blue 3 (**7**) and 268 mg of fluorescein disodium (**8**) were added (16 and 18 ppm, respectively). These two dyes were run simultaneously since their spectral signatures do not overlap. The Phosban reactor was charged with the indicated amount of pre-washed Hydrocarbon2 GAC (see Table 2), and an Eheim1048 pump was used to remove water from the bucket, push it through the Phosban reactor, and then return it to the bucket in a closed loop arrangement. The pump was adjusted to a flow rate of 49 gph (0.81 gpm). Samples of the reservoir water were removed at specific time intervals, typically every 5 - 15 min over a 120 - 180 min time course, and these samples were assayed for dye content with the Beckman DU70 UV/VIS spectrophotometer. As with the Langmuir isotherm experiments, the blue dye signal was monitored at 645 nm, and the fluorescein signal was monitored at 490 nm. No effort was made to adjust the solution temperature, which typically increased from 72 to 75 ^{o}F during the run. If the GAC column in the Phosban reactor began to separate due to the vigorous water flow, the cylinder was gently tapped until the GAC particles repacked into a single column. Control experiments (dye + salt water/no GAC) demonstrated that the dyes did not decompose over the experimental time regime.



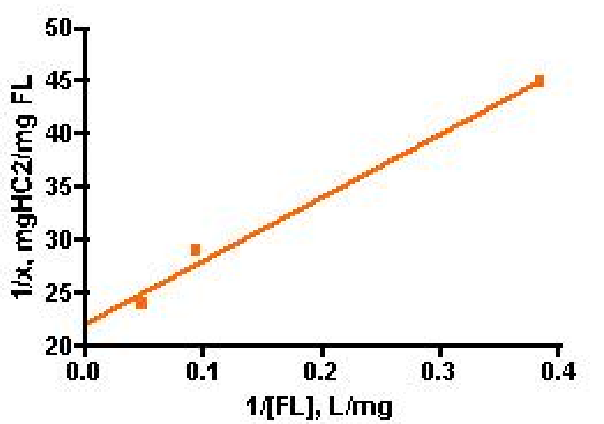


Figure 3. Graphical representation of the Langmuir isotherm experiment. BB3 is on the top (r^2 = 0.94), and fluorescein is on the bottom (r^2 = 0.99).

Figure 4 below shows the amount of dye remaining (as the quantity ($[dye]_t/[dye]_0$)) as time progresses for five different amounts of HC2: 25 gm, 50 gm, 75 gm, 100 gm, 150 gm, and 200 gm. Each individual experiment was replicated 2-3 times, but only a single representative data set is shown on the graphs for simplicity of presentation. These HC2 amounts span a range from about 6 to 50 gm/gal, and correspond to filling the Phosban reactor from 0.8" to 6.5" in height with the Hydrocarbon2. Some useful interconversions are:

(16) Grams of HC2 = 31 • height of the HC2 column, in inches

(17) Grams of HC2 = 81 • cups of the HC2

Inspection of the graphs indicate that indeed, the amount of blue dye (left) and fluorescein (right) remaining decreases over time, and that the rate at which the amounts decrease depends on the amount of GAC present. The mathematic treatment derived in Eq. (13) can be used to process these raw data into the desired quantity, k, the rate constant for dye removal (Table 2). Since both BB3 and fluorescein were run together, we can only report an averaged rate constant for them both. This simplification is in line with the expectation that in an aquarium setting, the DOC that GAC removes is quite heterogeneous, and average values for a compilation of compounds are probably more valuable than the rate constant value for any particular compound. The rate constants shown in Table 2 are the average values from the 2-3 independent runs for each set of unique experiments. In addition, the r^2 values for the data are given; these numbers reflect how accurately the mathematical model fits the data. Any value of r^2 greater 0.9 is good, and any r^2 values over 0.98 indicated an exceptionally solid correlation between the model and the data.

As discussed earlier, all of the calculated k's should be identical, since k is independent of the amount of GAC present. The fact that they are not requires some interpretation. The rate constant values for each dye when GAC ≥ 75 gm do indeed approach this criterion, lending confidence to the mathematical model for GAC-based dye removal in this GAC range. However, the rate constants k for the 25 and 50 gm of GAC runs are anomalously small. A possible explanation for this discrepancy emerges upon consideration of the actual manner in which the GAC packs into a bed in the Phosban reactor. It is possible, for example, that at the low HC2 loadings (25 and 50 gms), the shallowness of the GAC bed (< 1" for the 25 gm runs) allows channeling of the current, which in turn leads to GAC dead spots and diminished

Table 2. Figures of merit for the removal of Basic Blue 3 and Fluorescein (combined) by varying amounts of HC2; flow rate = 49 gph.

		Amount of HC2, gms					
		25	50	75	100	150	200
Basic Blue 3 andFluorescein	k (L/mol-min)	9.6 ± 0.6	13 ± 0.7	27 ± 0.5	21 ± 1	31 +2	28 ± 1
	r^2	0.97	0.99	0.99	0.98	0.98	0.99
	t_{90} (hr)	22	7.1	2.2	2.2	0.99	0.81

opportunities for dye binding. As the GAC amount increases, the bed becomes thicker, channeling is reduced, and more of the GAC charge can be utilized in dye binding. In this scenario, the higher loadings of HC2, which correspond to the more realistic GAC bed depths of 2.5 - 6.5", operate normally, and would fall under the purview of a typical Phosban charge in an aquarium setting. The k values between 75 and 200 gms of HC2 vary from 21 to 31 L/mol-min, a spread of about 20% (ave = 26 ± 5 L/mol-min). Given the assumptions used and all of the other possible experimental variables, this level of variation is not very surprising, and it is a reminder that we will likely only be able to draw approximate and not numerically precise conclusions from this analysis. *However, one early conclusion can be drawn from these data: using less that 75 gm of GAC (< 2.5 inches) in a Phosban reactor is not an effective way to utilize GAC for impurity removal.*

The time required to remove 90% of the dye (t_{90}, see Eq. (14) and the accompanying discussion) can be calculated for these experiments as well, see Table 2. These t_{90} values are specific to the conditions of the dye removal experiment (i.e., functions of flow rate and volume, mass of HC2, and the starting dye concentration). By plotting the t_{90} values as a function of the amount of HC2, the complex relationship between the quantity of HC2 and the rate of dye removal is revealed. These data are presented in Figure 5. It is apparent from inspection of Figure 5 that once a charge of 75 gm of HC2 (or greater) is used, the t_{90} values do not change much. Since the t_{90} values are a function of the rate constant k, and k does not change much in this HC2 range, this observation is not surprising. One interpretation of this trend is that when HC2 amounts above the 75 gm threshold are used, a large excess of HC2 binding sites are available compared to the amount of dye present, and so the dye molecules always "see" binding sites. This hypothesis is buttressed by the fact that 511 mg of dye in total is used in each experiment, and with an average binding capacity of 53 mgs of dye per gram of HC2 (from the calculated x_m above), only about 10 grams of HC2, in principle, is required to sop up all of the dye. Of course, since there is a great heterogeneity of binding sites, it would take a long time (recall the Langmuir binding experiments took over 14 days to reach equilibrium) to saturate all of the slow-binding sites. And so, it appears empirically that in the region above 75 grams of HC2, there are enough fast-binding sites to absorb the dye over the course of the 2-3 hour experiment. It is likely that in an aquarium, the fast binding sites are responsible for most of the absorption as well.

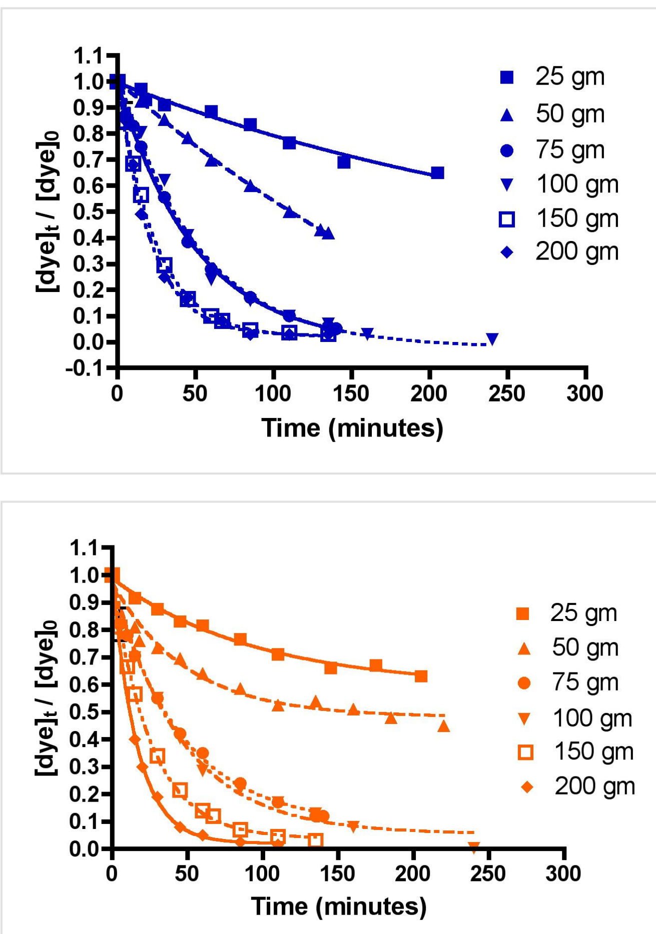


*Figure 4. Basic Blue 3 (**7**) (top) and fluorescein (**8**) (bottom) removal by Hydrocarbon2 GAC as a function of GAC amount.*

Rate of Dye Removal as a Function of Dye Structure and of Flow Rate

The next series of experiments probed two independent questions:

1. How does the chemical structure of the dye molecule influence its rate of removal by HC2?
2. How do dye removal rates respond to changes in the flow rate through the Phosban reactor?

The first question was examined by choosing one arbitrary set of experimental parameters (flow = 49 gph, 100 gm of Hydrocarbon2, 15-21 ppm of each dye molecule in a volume of 4 gallons) and measuring the decrease in dye absorption for the four dyes chosen, Basic Blue 3 (**7**) and Fluorescein (**8**) combined, Acid Yellow 76 (**9**) and Chlorophyllin (**10**). The choice of a 100 gram Hydrocarbon2 charge should put these experiments in the "constant k" regime of dye removal (cf. Table 2) where channeling through the GAC is not important. The Basic Blue 3 and Fluorescein 100 gm Hydrocarbon2 results are already described in Section 2.2. The remaining two dyes, **9** and **10**, were run separately since there was insufficient spectral dispersion to make

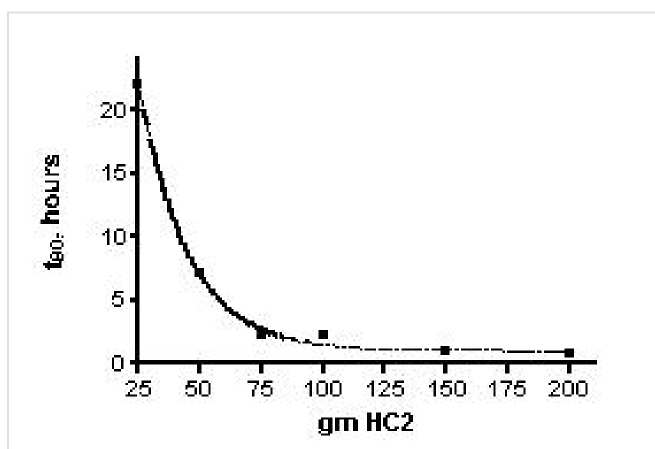


Figure 5. t_{90} values for dye removal as a function of the amount of HC2 used.

meaningful measurements in mixtures. In addition, both **9** and **10** were not soluble at the 15 ppm level in 35 ppt salt water. Therefore, these two dyes were examined in pure distilled water. This change in media raises obvious concerns about the relevance of the data acquired to questions of reef tank DOC removal. In order to address these concerns, a mixture of Basic Blue 3 (15.9 ppm) and Fluorescein (17.5 ppm) in *pure distilled water* was subjected to a HC2 removal run at 72 gph with 50 gm of HC2 (this issue was probed before we realized the benefits of using an HC2 amount greater than 75 gms). The measured rate constant for dye removal under these circumstances (k = 5.7 ± 0.3 L/mol-min) does differ from the same values obtained in salt water under identical experimental conditions (k = 4.1 ± 0.2 L/mol-min), and so some caution is necessary in interpreting the dye-to-dye comparison data. However, the discrepancy is not large, and so it will not affect the overall tenor of the conclusions.

A second independent series of dye removal experiments was conducted at a higher flow rate, 72 gph. These flow rate values (49 and 72 gph) span the range of suggested flow rates supplied with the Phosban reactor. The data are presented in Figure 6 and Table 3.

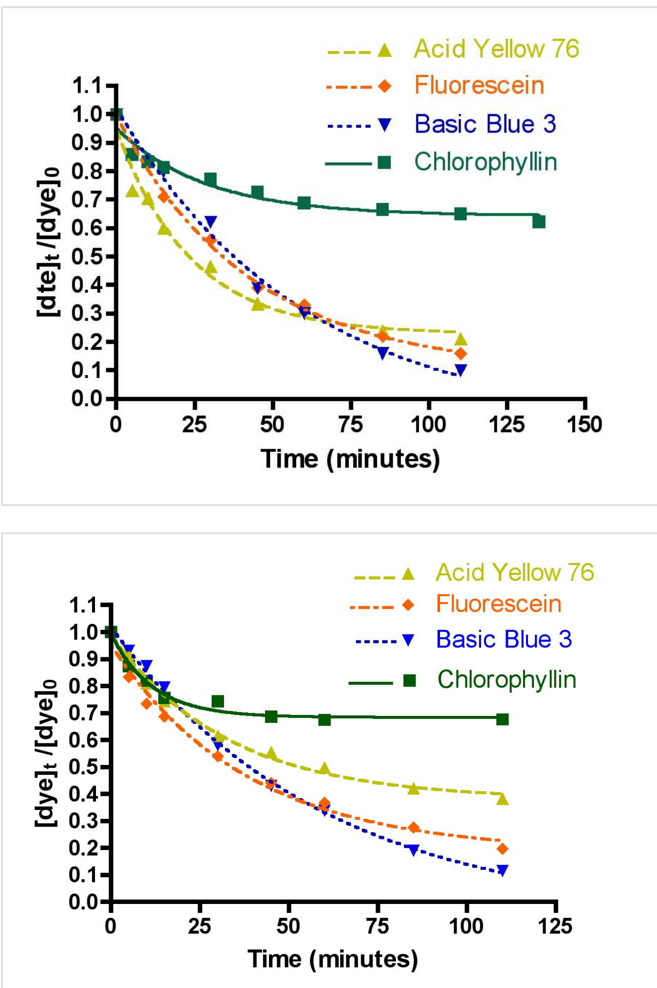


Figure 6. Basic Blue 3, Fluorescein, Acid Yellow 76 and chlorophyllin removal as a function of time. Top: 49 gph.; Bottom: 72 gph. (100 gms of Hydrocarbon2, 15-21 ppm dye each).

Table 3. Figures of merit for four different dyes upon removal by 100 gms of Hydrocarbon2 at two different flow rates.

dye		flow rate (gph)	
		49	72
Basic Blue 3 andFluorescein	k (L/ mol-min)	21 ± 1	18.0 ± 0.3
	r^2	0.98	0.99
	t_{90} (hours)	2.2	2.4
Acid Yellow 76	k (L/ mol-min)	14.1 ± 0.6	7.7 ± 1
	r^2	0.97	0.92
	t_{90} (hours)	3.0	5.4
Chlorophyllin	k (L/ mol-min)	2.6 ± 0.3	2.1 ± 0.4
	r^2	0.94	0.80
	t_{90} (hours)	16	20

The question of dye removal rate as a function of dye structure can be addressed in a general sense by considering the graphs depicted in Figure 7. It is clear from inspection of these graphs that the rate of dye removal does vary as per the dye structure. This variation can be quantified by application of Eq. (13) as described in the Mathematical Modeling section, and the values of the derived rate constants are presented in Table 3. The differences in rates of removal are not large, however, and vary no more that a factor of 10 between fastest (Basic Blue 3/Fluorescein) and slowest (Chlorophyllin).

The experimental observation that the rate constants for dye removal, k, *decreased* at the faster flow with all of the dyes was unexpected. Intuitively, an *increase* in the rate constant for dye removal might be expected to result from a situation in which more dye-containing solution passes through the GAC bed per unit time (i.e., faster flow rate). How can this discrepancy be rationalized? In fact, it is typical for flow-through reactor experiments such as the one used in these studies to find that mass transfer of the solute (= dye molecules in this case) from the bulk solution to the adsorption site is actually the slow, or rate-limiting, step. Since the rate constant can be thought of as a probability of adsorption as the solution passes through the GAC layer, the residence time of a given dye molecule becomes important. If the residence time is long compared with the time it takes for the dye molecule to find its adsorption site, then the k value will be high. On the other hand, if the residence time is short compared to the time it takes for the dye to find its adsorption site, then the k value will be smaller. Residence time scales inversely with flow rate, so it is possible that we have entered a regime where the faster flow (= less residence time) lead to lower k's. Some experimental evidence that supports this conclusion can be found in Figure 7, where the k values scale inversely with the molecular weight of the dyes. This behavior is consistent with a scenario where mass transfer in solution, which also scales inversely with increasing molecular weight, is a significant factor in the overall kinetics. That is, the more a molecule weighs, the slower is its transit from point A to point B in solution, and so it benefits (= larger k) from a longer residence time in the GAC bed (= slower flow rate).

Is it possible to delve deeper into these rate vs. structure differences and arrive at some correlation between the rate constant for dye removal and some measurable molecular parameter? If such a relationship can be discerned, then these model dye experiments may have some predictive value in terms of removal efficiencies for the types of compounds that have been proposed

as components of DOC in the marine environment. We examined the correlation between dye removal rate constants k and three molecular parameters: molecular weight, molecular volume, and molecular surface area of the dye. The former value is just the sum of the weights of the component atoms. The latter two values were calculated by using a commercially available computational chemistry program called *Spartan* [Spartan'04], one of the standard tools of chemists who work with complex organic molecules. The data are plotted in Figure 8. As can be seen by inspection of these graphs, there is significant correlation between each of the molecular parameters and the rate constant for dye removal, k. Perhaps a larger data set of structurally different dyes might have yielded even more compelling relationships, but at the very least, there does appear to be a trend among these data sets: molecules with smaller molecular weights/volumes/surface areas appear to be removed faster by HC2. Thus, GAC might be better at removing the smaller molecular metabolites, colored or uncolored, that are inevitably produced in marine tanks compared to the larger biomacromolecules (or large fragments thereof), such as proteins, polynucleic acids, and oligosaccharides that also are present. As discussed earlier, this k dependence on size may be largely attributed to the inverse relationship between molecular weight and mass transfer in solution.

Leaching Experiments: Does Saturated GAC Release Bound Dyes?

How well do the dyes stick to the GAC particles? Do the dyes (and by inference, DOC's) leach back out into solution over time? Actually, just such leaching in the context of equilibrium binding is a requirement for application of the Langmuir isotherm model to measuring dye saturation points. In the context of aquarium chemistry, this concern becomes particularly relevant if the GAC in an aquarium setting is not changed out prior to saturating. At that point, will it serve as a DOC source, slowly polluting the aquarium water?

This question was examined by recovering the used HC2 from Chlorophyllin and Basic Blue 3 adsorption experiments, washing it with distilled water, and then resuspending it in the Phosban reactor. Distilled water was added to the reservoir and the Phosban reactor in the usual amounts (4.0 gallons), and the Eheim pump was turned on to 49 gph. The dye content of the reservoir was measured at the indicated time intervals (Figure 8). For these experiments, the $[\text{dye}]_o$ measurement was taken a few minutes after adding the dye-saturated HC2 to the pure water. Therefore, the $[\text{dye}]_t/[\text{dye}]_o$ ratio should increase over time, as more dye diffuses out of the HC2. From these data, it appears that both Chlorophyllin and Basic Blue 3 leach out in observable and significant quantities over the course of several hours. The Chlorophyllin concentration ultimately diminishes, but based upon the color changes observed at long experimental times, it is possible that this species is undergoing some type of chemical destruction (oxidation? demetalation of the porphyrin core?) in competition with HC2 binding. Extrapolating from these dye results to DOC in the aquarium requires the usual caveats, of course, but these observations are suggestive of the fact that organics may not stay stuck to GAC over time. This tentative conclusion raises the concern that keeping saturated, or spent, GAC in the system past its useful life may be problematic. Is there a way to "guestimate" when the GAC is saturated? Section 3.2 will address this point.

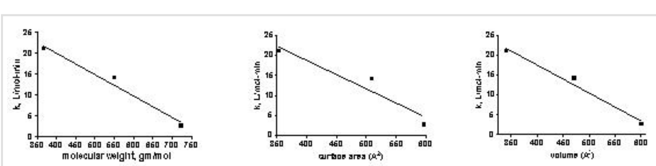


Figure 7. Rate constant, k, for the different dyes vs. measurable molecular parameters.

These leaching results do not negate the assumption underlying the kinetic analysis described in the Mathematical Modeling section, as long as the rate of removal data were recorded under an experimental protocol were the Hydrocarbon2 was not saturated. Given that the experiments were conducted under a regime where a large excess of HC2 binding sites compared with dye were evident (at least for ≥ 75 gms of HC2), it does not appear that saturation of the HC2 samples was achieved, and hence dye leaching during the trials is not likely to compromise the data.

GAC Comparison: Hydrocarbon2 vs. Black Diamond

A brief comparison of two different GAC's, Hydrocarbon2 from Two Little Fishes and Black Diamond from Marineland, was pursued. For these trials, a 50 gm charge of GAC was used, the flow was set at 49 gph, and all four dyes were examined. The choice of a 50 gram GAC charge was made prior to the discovery that GAC amounts below 75 gm led to suboptimal rate constants (cf. Table 2). Therefore, it is not appropriate to compare directly the rate constants reported in Table 4 below, which were derived from the 50 gm GAC charges, with the maximal values from Table 1 derived from the 75 - 200 gm Hydrocarbon2 charges. Nevertheless, the *relative* rate constants for the different dyes from these 50 gram GAC experiments should be directly comparable, and the conclusions drawn from these comparisons should be unaffected by the channeling problems posited earlier with the < 75 gm Hydrocarbon2 charges.

Figure 9 displays the change in concentration of the four dyes as time increases for both Black Diamond and Hydrocarbon2. As noted earlier, Basic Blue 3, Acid Yellow 76 and Fluorescein all behave similarly to each other, but chlorophyllin is adsorbed by

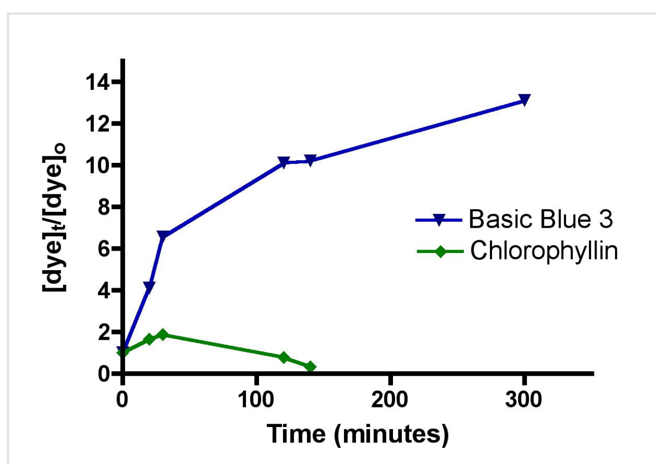
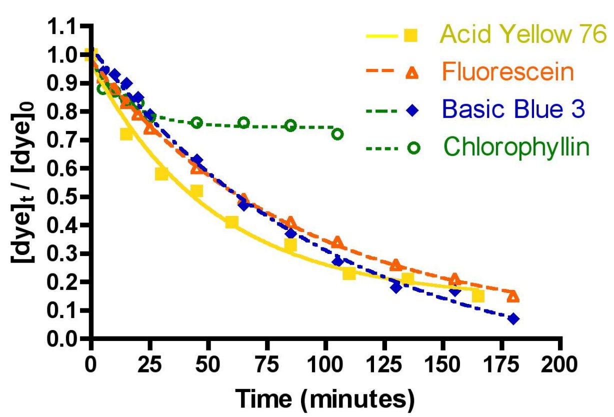


Figure 8. Leaching of both Basic Blue 3 and Chlorophyllin from Hydrocarbon2 infused with the dyes.

Black Diamond no better than it is by Hydrocarbon2. However, there is a conspicuously steeper drop-off in dye concentration for the other three dyes with Black Diamond compared to Hydrocarbon2. This steeper drop-off is reflective of a larger rate constant for dye removal, and these differences can be quantified using Eq. (13), as shown in Table 4.

For the three dyes that do seem to be susceptible to significant adsorption by GAC (Acid Yellow 76, and Fluorescein/Basic Blue 3 combined), the rate constants k for dye removal are approximately twice as large with Black Diamond as they are with Hydrocarbon2. Correspondingly, the derived t_{90} values with Black Diamond are about half of those with Hydrocarbon2. These data lead to the clear conclusion that Black Diamond removes these dyes more rapidly than Hydrocarbon2, and by inference, DOC in general. Whether the factor-of-two difference with the dyes translates to a similar ratio with authentic DOC removal in a marine tank is unknown, but it seems likely that the large advantage enjoyed by Black Diamond for dye removal will lead to enhanced rates of organic clearance for the aquarist.



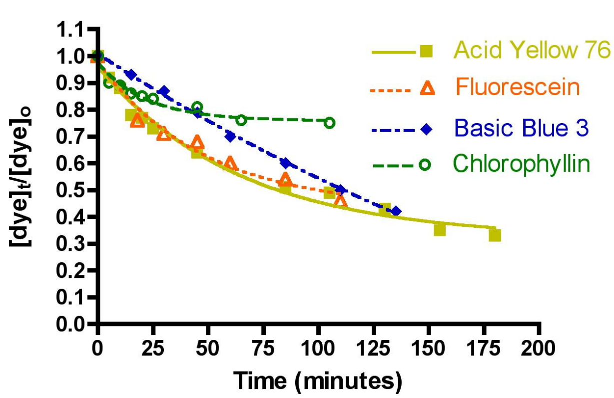


Figure 9. Dye removal by Black Diamond (top) and Hydrocarbon2 (bottom) at 49 gph flow, using 50 gm of GAC.

Table 4. Figures of merit for the comparison of HC2 and Black Diamond GAC's, using 50 gm of GAC, 49 GPH flow rate.

dye		GAC	
		HC2	Black Diamond
Basic Blue 3 andFluorescein	k (L/ mol-min)	13 ± 0.7	28 ± 1
	r^2	0.99	0.99
	t_{90} (hours)	7.1	3.3
Acid Yellow 76	k (L/ mol-min)	11.9 ± 0.7	23 ± 1
	r^2	0.97	0.98
	t_{90} (hours)	7.3	3.8
Chlorophyllin	k (L/ mol-min)	3.7 ± 0.4	3.9 ± 0.7
	r^2	0.79	0.83
	t_{90} (hours)	23	21.6

Aquarium Applications

How much GAC should I Use?

The answer to this question really depends on what the goal is. There are arguments for removing impurities rapidly (clearing a toxic substance) and for removing them slowly (don't shock the corals with more light penetration), and so no one best GAC amount will fit all circumstances. Nevertheless, the data presented below (Figure 10) might be useful in establishing guidelines for selecting the appropriate amount of GAC for a given situation. These graphs illustrate the calculated time (in hours) required to *cut the amount of DOC by 90%* as a function of the mass of HC2 used, the tank water volume, and *the amount of DOC assumed to be initially present*.

What is the justification for the assumption that certain amounts of DOC are present? More succinctly, "Just how much DOC is in reef tank water?" Due to a lack of adequate assay methods at present, this quantity, while crucial to any DOC removal technology, can only be approximated. A reef tank has a certain amount of DOC present as a consequence of a balance between DOC production and DOC removal (by any method), but how can that amount be quantified?

Commercially available DOC measurement kits are uniformly disappointing in that they only detect a small class of organic substances. As part of an ongoing study of protein skimmer efficiency in removing proteins and other DOC from aquarium tank water, we are exploring an oxidation-based assay procedure for DOC quantification that utilizes commercially available protein measurement kits. Although it is beyond the scope of this article to elaborate on this procedure (see coming attractions: "Quantitative Evaluation of Protein Skimmer Performance"), our preliminary assays of both skimmed-and-GAC-treated and unskimmed/no-GAC marine tank water reveal DOC levels on the order of 0.5 - 1 ppm for GAC/skimmed tanks and 5-10 ppm for no-GAC/unskimmed tanks. Specifically, oxidizable organic levels from three skimmed and GAC-treated reef tanks and one fish-only tank are: 0.40 ppm, 0.42 ppm, 1.3 ppm, and 1.3 ppm. Similarly the oxidizable organic levels in two unskimmed/no-GAC reef tanks (soft corals, invertebrates and a few fish) are: 4.5 and 8.5 ppm. Since our assay only detects oxidizable organics, it is likely to underestimate the actual amount of DOCs, but probably not by a great amount. That is, the oxidizing agent employed in the assay is powerful enough to oxidize (and hence detect) molecules from many of the compound classes illustrated in Figure 1. We plan to

employ this assay with specific members of these molecular classes to test this assumption, but those studies remain for the future. This admittedly small sample size will be taken as representative for the purpose of the calculations below. To incorporate these oxidizable organic concentration values in the calculations, we will use as arbitrary starting points the values of 1.0 ppm of DOC and 7.5 ppm of DOC to represent "cleaner" and "dirtier" tanks, respectively. It will be of some interest to obtain samples of aquarium water out of a wide range of tanks from the greater reefkeeping community to expand upon this data set and see if consensus values emerge for oxidizable organics that correlate to different husbandry techniques, or to determine if the oxidizable organic level varies significantly, for example, when the lights are on or off, or during the period after a tank feeding. Those studies are in the future. Of course, continual replenishment of DOC's by active biological processes (at an unknown rate) would ensure that DOC removal would never be complete! However, it is only necessary to remove DOC at a rate commensurate with, or faster than, the rate of DOC production in order to bring the DOC levels down to some arbitrarily low value.

The same mathematical approach discussed in Section 1.4 can be used to address the more interesting question for aquarists: how long will it take to remove, say, 90% of the DOC from the initial starting point of either 1 ppm or 7.5 ppm? In this case, Eq. (14) is used, but with new values for the water volume and the initial concentration of the DOC (equivalent to 1 and 7.5 ppm, respectively, of an average 400 molecular weight compound). The values of m and k are those extracted from the BB3/Fluorescein removal experiments - hence, the value of the dye system as a model for DOC removal in an aquarium. An average x_m value of 53 mg of DOC/gm of GAC is used, which is based solely on the BB3/Fluorescein Langmuir isotherm experiments. It is possible, even likely, that other dyes (or more generally, other organic structures that are components of DOC) have different saturation values. The measurement of a larger collection of x_m values corresponding to a range of plausibly DOC-like molecules will have to await further experimentation. Nevertheless, we have correlated k and x_m values only for the BB3/Fluorescein dyes, and so we will confine our further analysis to these inputs. The results are displayed in Figure 10, with the 1 ppm DOC data on the left, and the 7.5 ppm DOC data on the right.

The curves in these graphs can be fitted to the expressions shown in Eqs. (18 - 27) below, where t_{90} is the time, in days, required to deplete the DOC level to 10% of its original value, for a given amount of HC2 (indicated by "gm"). These mathematical relationships are strictly empirical and should not be extrapolated beyond the HC2 data range. Note that in the 7.5 ppm DOC case, the 200 gallon water volume contains too much DOC to be 90% absorbed by amounts of HC2 less than ~ 100g.

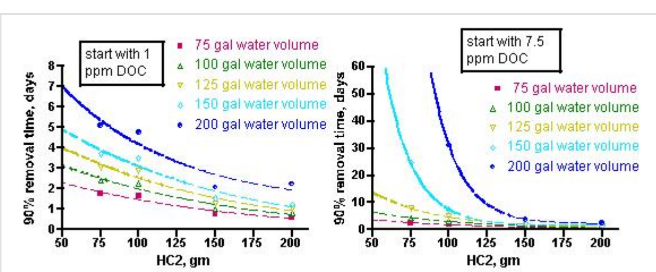


Figure 10. Calculated time for removal of 90% of DOC at starting points of 1 ppm DOC (left) and 7.5 ppm (right), as a function of tank water volume and amount of HC2 used.

(18) (1 ppm DOC, 75 gallon) $t_{90} = 3.7e^{(-0.008 \bullet (gm))} - 0.2$, $r^2 = 0.92$

(19) (1 ppm DOC, 100 gallon) $t_{90} = 5.1e^{(-0.0081 \bullet (gm))} - 0.3$, $r^2 = 0.93$

(20) (1 ppm DOC, 125 gallon) $t_{90} = 6.5e^{(-0.0084 \bullet (gm))} - 0.3$, $r^2 = 0.93$

(21) (1 ppm DOC, 150 gallon) $t_{90} = 8.0e^{(-0.0084 \bullet (gm))} - 0.4$, $r^2 = 0.93$

(22) (1 ppm DOC, 200 gallon) $t_{90} = 11.4e^{(-0.013 \bullet (gm))} + 1.2$, $r^2 = 0.89$

(23) (7.5 ppm DOC, 75 gallon) $t_{90} = 6.7e^{(-0.012 \bullet (gm))} + 0.04$, $r^2 = 0.96$

(24) (7.5 ppm, 100 gallon) $t_{90} = 14e^{(-0.016 \bullet (gm))} + 0.3$, $r^2 = 0.98$

(25) (7.5 ppm DOC, 125 gallon) $t_{90} = 41.2e^{(-0.023 \bullet (gm))} + 0.74$, $r^2 = 0.99$

(26) (7.5 ppm DOC, 150 gallon) $t_{90} = 1441e^{(-0.055 \bullet (gm))} + 1.8$, $R^2 = 0.99$

(27) (7.5 ppm DOC, 200 gallon) $t_{90} = 8001e^{(-0.056 \bullet (gm))} + 2.3$, $r^2 = 0.99$

How might an aquarist use this information to answer the question "How much GAC should I use?" The aquarist will have to estimate the water volume of the system (for an accurate and simple way to calculate system water volumes, see http://www.reefkeeping.com/issues/2006-04/pr/index.php, Experiment 3), and then make a guess as to whether their tank has a low level of DOC's (~ 1 ppm in a system with adequate nutrient removal) or a high level (~ 7.5 ppm in a system with poor/absent nutrient removal). For example, a system with 150 gallons of total water volume that is adequately skimmed (or subjected to other effective nutrient removal, assume [DOC] = 1 ppm) would be characterized by the aqua curve on the left-hand graph in Figure 10. By interpolating from that curve (or, more quantitatively, by using the expression of Eq. (21)), an aquarist can conclude that a 200 gram charge of HC2 should remove about 90% of the DOC in approximately 1.1 days, but a 75 gram portion of HC2 would take approximately 3.9 days to achieve the same result.

Of course, DOC is continually being introduced via feeding and metabolic processes, and so the ultimate question of how much GAC to use in order to deplete the DOC concentration to some arbitrarily low target value in the aquarium requires knowledge of the rate of DOC production and not just the rate of DOC removal. Since this former quantity is not measurable by any simple means, only half an answer is possible at this point in the analysis (however, see Section 3.2). Of course, using a larger charge of HC2 would be more likely to allow the aquarist to "keep ahead" of the DOC production rate.

When Should I Change My GAC?

The useful lifetime of a GAC charge will depend on a host of factors, including the amount of GAC employed, the tank water volume, and the steady-state level of DOCs present. For the purpose of these calculations, we define a quantity, t_{90}, as the time

when 90% of the GAC's DOC absorption capacity has been utilized. Using the experimentally determined k values from Table 2, the 53 mg-of-dye/gm-of-HC2 saturation value derived from Table 1, and an arbitrary starting DOC concentration (either 1 ppm or 7.5 ppm as per the discussion in Section 3.1), the KinTekSim program can decipher the kinetics of Eq. (15) and calculate the concentrations of [DOC] and [GAC_{bs}] as a function of time, when both [PoOP] and k_1 are user-defined inputs. One important test of any kinetics simulation approach for extracting useful information from complex systems is the ability to reproduce experimental data with fidelity. Towards this end, we examined the simulated removal of DOC from tank water with the DOC input mechanism turned off ([PoOP]•k_1 set to 0). This test simulation is equivalent to the simple Eq. (1) case, and the calculated output of [DOC] as a function of time matched closely the experimental data shown in Figure 4, at least for the 3 cases examined: 50, 100, and 200 gms of HC2 in the 4 gallon volume of the experimental reservoir.

For the initial [DOC] = 1 ppm series, we examined [PoOP]•k_1 values spanning the range of 0.1 ppm/day to 1 ppm/day for a 100 gallon water volume and a 100 gm HC2 charge (chosen to be in the middle of the water volume and GAC amount ranges), and recorded the calculated average DOC levels during the time t = 0 days to t = t_{90} days. The goal of this exercise was to iterate through the [PoOP]•k_1 values until readings for $[DOC]_{ave}$ fell into the experimental range of ~ 0.5 - 1.0 ppm observed in actual marine tanks (see section 3.1).

The range of [PoOP]•k_1 values that met this criterion centered around 0.2 ppm/day, and so for the range [PoOP]•k_1 = 0.15 - 0.35 ppm/day, we expanded our calculations to include "extreme" values of tank water and GAC used, in the hopes of capturing the full spread of [DOC] amounts that might emerge from these simulations. These data are recorded in Table 5. A similar approach was employed for the dirtier tank, using [DOC] = 7.5 ppm as the starting point. These latter calculations required substantially greater DOC introduction to achieve the $[DOC]_{ave}$ » 4 - 8 ppm level, and the relevant [PoOP]•k_1 values turned out to be an order-of-magnitude higher that in the cleaner tank case where the initial [DOC] = 1 ppm. Is this a realistic outcome? It is important to recognize that the aquarium water which measured ~ 4 - 8 ppm of oxidizable organics with our protein assay was taken from unskimmed tanks, whereas the water that measured 0.5 - 1 ppm of oxidizable organics was taken from skimmed tanks. Our simulations do not account for any other methods of nutrient removal besides GAC, so skimming or water changes are not recognized. Therefore, in order to elevate $[DOC]_{ave}$ to the ~ 4 - 8 ppm level characteristic of the unskimmed ("dirty") tanks for these simulations, we cannot remove less DOC (as implied by the absence of skimming) and so we must increase the rate of DOC introduction (larger [PoOP]•k_1).

Since all of the calculated $[DOC]_{ave}$ values in Table 5 fall within the experimental ranges of measured tank oxidizable organic levels, which values do we choose to continue on with the simulations? Since the tank water assay detects only oxidizable organics, it seemed prudent to choose a higher end value to account for the undetected non-oxidizable components of DOC. For this reason, we selected [PoOP]•k_1 = 0.30 ppm/day at 1 ppm of starting DOC as the input rate of DOC production for the remaining simulations, and [PoOP]•k_1 = 3.0 ppm/day for the simulations starting with 7.5 ppm of DOC. Once a [PoOP]•k_1 value is chosen, it must be used for all of the other tank-volume/GAC-amount variations examined in the respective 1 ppm or 7.5 ppm DOC series, as [PoOP]•k_1 will not scale with either water volume or GAC mass. This constraint leads to some spread in the data, as not every volume/GAC pairing will be best described by [PoOP]•k_1 = 0.30 ppm/day.

The influence of the specific [PoOP]•k_1 value on the desired calculated quantity, t_{90}, can be seen from inspection of the data in Figure 11. These graphs depict the calculated DOC and GAC_{bs} concentrations as a function of time for a 100gallon/100 gm HC2 simulation, at different [PoOP]•k_1 values (upper: 1 ppm starting DOC. lower: 7.5 ppm starting DOC). The intersections of the GAC_{bs} lines with the t_{90} lines indicate the time required to saturate 90% of the HC2 with DOC. Quantitatively, for the 1 ppm starting DOC series (upper graph): for [PoOP]•k_1 = 0.25 ppm/day, t_{90} = 49 days; for [PoOP]•k_1 = 0.30 ppm/day, t_{90} = 41 days, and for [PoOP]•k_1 = 0.35 ppm/day, t_{90} = 36 days. So, if we guessed wrong for the [PoOP]•k_1 value by 17%, we introduce a spread of about 14% into the final t_{90} values. That is, a spread in $[DOC]_{ave}$ of 0.75 - 0.98 ppm (from Table 5) correlates to t_{90} values of 36 - 49 days, or for the 100gallon/100gm case, the GAC will be 90% saturated at around 41 ± 6 days. Similarly, for the 7.5 ppm starting DOC series (lower graph), the following t_{90} values can be gleaned: for [PoOP]•k_1 = 2.0 ppm/day, t_{90} = 5.0 days; for [PoOP]•k_1 = 3.0 ppm/day, t_{90} = 3.9 days, and for [PoOP]•k_1 = 4.0 ppm/day, t_{90} = 3.3 days. Once again, estimating [PoOP]•k_1 incorrectly by 33% leads to an 18 - 28% error in the calculated t_{90} values. These potential errors carry much less significance in the starting [DOC] = 7.5 ppm case compared with the starting [DOC] = 1 ppm series, since the t_{90} values are so short. Basically, the HC2 saturates in just a few days, and it will likely matter little to the aquarist working under these conditions whether the exact saturation time is 3 days or 5 days. Given all of the assumptions that undergird this simulation, a conservative approach to interpreting these output values would seem prudent, and would require these rather large error bars. This lack of precision may be disquieting, but it is important to emphasize that the simulation results are clearly not consistent with, for example, a scenario where t_{90} values of 10 days or 100 days are calculated ([DOC] = 1 ppm case). This spread in the data is typical of kinetics simulations where the input

Table 5. The variation in calculated average DOC concentration ($[DOC]_{ave}$) and terminal DOC concentration ([DOC] at t_{90}; i.e., when the HC2 is 90% saturated) as a function of starting [DOC] and DOC generation rate [PoOP]•k_1. The $[DOC]_{ave}$ values were averaged over 5 sets of experimental inputs (gallons of tank water/gms of HC2): 75 /50, 75/200, 100/100, 200/50, and 200/200.

Starting [DOC] = 1.0 ppm			Starting [DOC] = 7.5 ppm		
[PoOP]•$k_1$ppm/day	**$[DOC]_{ave}$ ppm**	**[DOC] at t_{90} ppm**	**[PoOP]•$k_1$ppm/day**	**$[DOC]_{ave}$ ppm**	**[DOC] at t_{90}, ppm**
0.15	0.57	1.2	1.0	3.7	4.5
0.20	0.65	1.3	2.0	5.1	6.8
0.25	0.75	1.5	3.0	6.6	8.5
0.30	0.87	1.7	4.0	7.1	10.1
0.35	0.98	2.0	5.0	7.9	11.7

parameters are uncertain. As a last point, note how the DOC concentration begins to rise significantly when the GAC is 90% saturated - this behavior is entirely consistent with the physical reality of the tank getting dirtier via DOC production when the DOC removal mechanism shuts down.

An interesting observation to emerge from these simulations is that, at least for the 100 gallon water volume/100 gm of HC2 case described by Table 5 and Figure 11, the GAC saturation times vary tremendously depending upon the clean/dirty state of the tank water. Under conditions of aggressive DOC removal (skimming, water changes, GAC use), the GAC charge should last over a month, but under more passive nutrient removal husbandry (no skimming? no frequent water changes?), the GAC charge will be depleted in just a few days.

Extension of these simulations to a range of tank water volumes and GAC amounts will provide the aquarist with suggestions for GAC depletion times over a range of realistic usage scenarios. Using the [PoOP]•k_1 values of 0.3/ day and 3.0/day for the 1 ppm and 7.5 ppm of [DOC] cases, respectively, simulations covering tank volumes of 75 - 200 gallons and HC2 amounts of 50 - 200 gm leads to the family of linear relationships that are shown in Figure 12 (starting [DOC] = 1 ppm on the left side, and starting [DOC] = 7.5 ppm on the right side). Each line represents a different tank water volume, and expresses the relationship between the amount of HC2 used (X-axis) and the corresponding time-of-use until the HC2 is 90% saturated (Y-axis). These relationships can be expressed by the mathematical formulae Eq. (28) - Eq. (37) below. In principle, all of these lines should pass through the origin of the graph (t_{90} = 0 when there is no HC2 present). However, the best-fit lines have small and positive Y-axis intercepts. This deviation from ideality is again a reminder of the role that assumptions and experimental error plays in any laboratory enterprise. Fortunately, for this case, the non-zero Y-intercepts only amount to < 10% of the final t_{90} readings. These mathematical relationships are strictly empirical and should not be extrapolated beyond the HC2 data range.

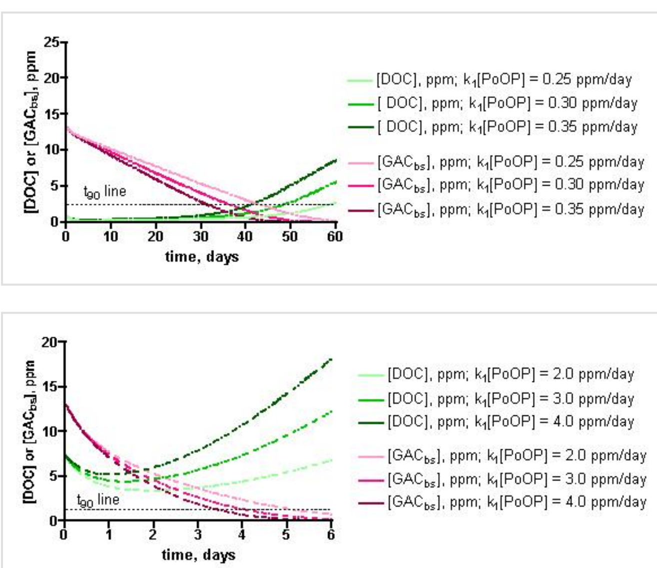


Figure 11. Examples of the KinTekSim output for a 100 gallon/100gm of HC2 simulation, using different values of the input parameter [PoOP]•k_1. Upper graph: 1.0 ppm DOC starting point. Lower graph: 7.5 ppm starting point.

(28) (1 ppm DOC, 75 gallon) t_{90} = 0.51•(gm) + 3.7, r^2 = 0.99

(29) (1 ppm DOC, 100 gallon) t_{90} = 0.37•(gm) + 5.2, r^2 = 0.99

(30) (1 ppm DOC, 125 gallon) t_{90} = 0.27•(gm) + 8.3, r^2 = 0.99

(31) (1 ppm DOC, 150 gallon) t_{90} = 0.23•(gm) + 6.2, r^2 = 0.99

(32) (1 ppm DOC, 200 gallon) t_{90} = 0.16•(gm) + 7.6, r^2 = 0.97

(33) (7.5 ppm DOC, 75 gallon) t_{90} = 0.046•(gm) + 0.22, r^2 = 0.99

(34) (7.5 ppm, 100 gallon) t_{90} = 0.032•(gm) + 0.57, r^2 = 0.99

(35) (7.5 ppm DOC, 125 gallon) t_{90} = 0.021•(gm) + 1.2, r^2 = 0.98

(36) (7.5 ppm DOC, 150 gallon) t_{90} = 0.016•(gm) + 1.3, R^2 = 0.94

(37) (7.5 ppm DOC, 200 gallon) t_{90} = 0.010•(gm) + 2.6, r^2 = 0.93

How might an aquarist use this information to answer the question "When should I change my GAC?" Much as with the "How much GAC?" question addressed in Section 3.1, the aquarist will have to estimate the water volume of the system, and then make a guess as to whether their tank has a low level of DOC's (~ 1 ppm in a system with adequate nutrient removal) or a high level (~ 7.5 ppm in a system with poor/absent nutrient removal). For example, a system with 150 gallons of total water volume that is adequately skimmed (or subjected to other effective nutrient removal, [DOC] ≤ 1 ppm) would be characterized by the aqua line on the left-hand graph in Figure 12. By interpolating from that line (or, more quantitatively, by using the expression of Eq. (31)), an aquarist can conclude that a 100 gram charge of HC2, for example, should be replaced in approximately 29 days, whereas a 200 gram portion of HC2 would last approximately 52 days before it became saturated with DOC's. In a similar manner, an aquarist running an unskimmed (i.e., [DOC] at approximately 7.5 ppm) 75 gallon tank could use the magenta line in the right-hand graph of Figure 12 (or Eq. (33)) to estimate that a 100 gm HC2 charge will become saturated with DOC's in approximately 4.8 days, and a 200 gm portion of HC2 would last about 9 days. Clearly, very nutrient rich tanks will require better means of DOC export than only GAC-based removal!

Conclusions

Aquarists who choose to use granular activated carbon (GAC) to aid in water purification are faced with two over-arching

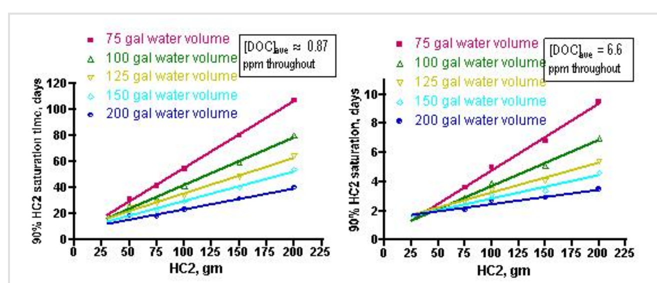


Figure 12. Calculated time to saturate 90% of the available HC2 binding sites as a function of amount of HC2, tank water volume, and starting DOC concentration (1 ppm (left) and 7.5 ppm (right)).

questions: "How much GAC should I use?", and "When should I replace my GAC?". Through a combination of experimentation using dyes as surrogates for dissolved organic carbon (DOC) and computer simulations of the DOC introduction/removal process, we can suggest tentative answers to these questions (Figures 10 and 12). The answers depend on three aquarist input quantities: the amount of DOC present, the amount of GAC used, and the tank water volume. The latter two metrics are easy to come by, but quantifying the amount of DOC present must still await reliable assay kits. Nevertheless, data from a small sampling of tanks provides guidance on this point, as both low-nutrient (~ 0.5 - 1 ppm of measurable oxidizable organics) and high-nutrient (~ 4 - 8 ppm of measurable oxidizable organics) water samples seem to correlate with either the presence or absence of an efficient protein skimmer. Certainly, a broader survey of marine tanks in the future will help refine these numbers.

In the final analysis, this study presents results that are based on model systems and not real operational marine tanks. We have made a case for the extrapolation of these model system conclusions to marine aquariums, but ultimately each aquarist will have to find their own comfort level regarding the validity of this connection.

Acknowledgment

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FEATURE ARTICLE

SUPER CORALS - SUPERMAN *MONTIPORA*

By Dana Riddle

The following article will examine some husbandry techniques for this exotic coral.

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Only a few corals can match this coral's startling contrast of colors, making the Superman *Montipora* a highly desirable animal for display reef aquaria. As can be expected, the demand for this coral ensures a premium price.

The following article will examine some husbandry techniques for this exotic coral. Since many of us are not particularly interested in how information within this article was obtained, I'll present the pertinent data first and will save the nitty-gritty technical details and methods for the end of this article.

Again, bear in mind that the details below are from a limited number of specimens, and other *Montipora* species may bear a resemblance to *M. danae* (be sure of the coral's ID!).

Common Name: Superman

Family: Acroporidae

Genus: *Montipora*

Variously described as these species: *Montipora danae* (which can be confused with*M. verrucosa, M. verruculosus and M. palawanensis.* The latter two species are uncommon and restricted to a smaller geographical area than the two former species). Also described in advertisements as *M. tuberculosa.* The coral in Figure 1 is likely *M. danae* as its immersed corallites are widely spaced between hillocky coenosteum verrucae (or tuberculae) and partially fused ridges. Identification is based on results obtained by using Veron's *Coral ID* software. See Comments below for basis of identification.

Geographical Range: Indian and Pacific Oceans and possibly the Red Sea.

Known Symbiont Types: *Symbiodinium* species, including Clades C2, C31, C+ and C·.

LIGHT REQUIREMENTS

Reef hobbyists, as a group, have the correct concept about lighting - it is an important factor in successful reefkeeping and probably the most expensive routine maintenance item in terms of electricity consumption. Yet relatively few own or use any sort of light meter. This is probably due to the fact that so little is known about light requirements of photosynthetic invertebrates. However, there are instruments available to determine how much light is actually required. As this information becomes available, we can arm ourselves with this knowledge and can potentially begin to put our reef aquaria on energy diets. In short, a light meter is a good investment.

At a minimum, hobbyists should have (or have access to) a lux meter with a submersible sensor or, even better, a quantum meter for measuring Photosynthetically Active Radiation (PAR, reported in units of micro Mol photons per square meter per second, or μmol photons·m^2·sec, but usually just μmol·m^2·sec.

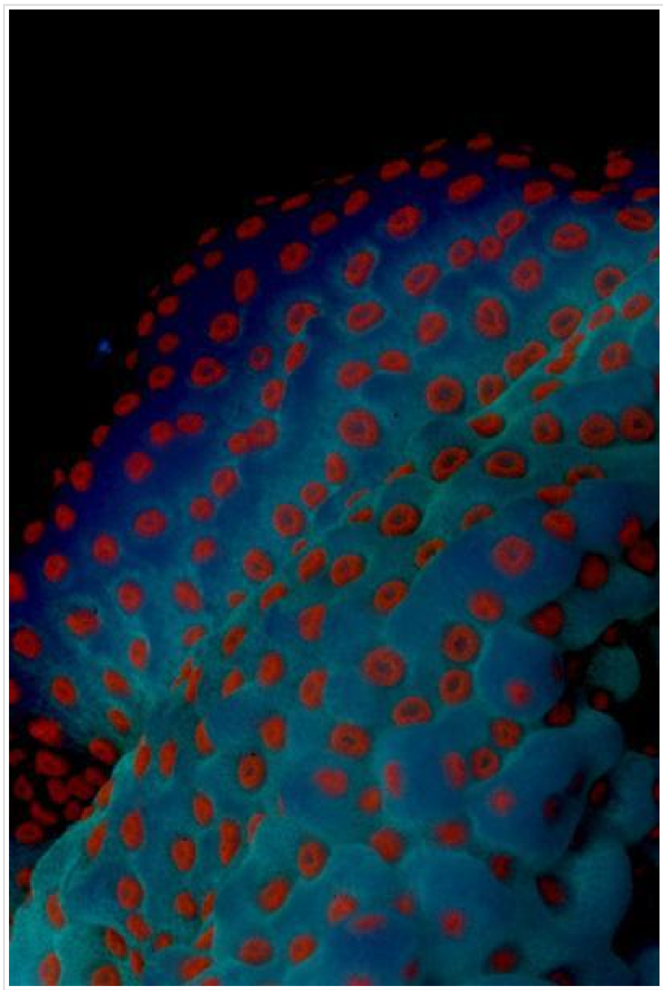

Figure 1. A Superman Montipora.

Maximum PAR in the tropics at noon on a cloudless day can be as high as 2,200 µmol·m²·sec).

Although either of these instruments is relatively expensive, the price of a quality meter has dropped dramatically over the last decade or so. No longer is it necessary to spend over $1,000 for a PAR meter - quite adequate units are available for ~$250.

I have to wonder what state the hobby would be in if we treated many of the established parameters in the manner many treat light intensity. What if we were advised to maintain either a high or low pH? Alkalinity? Phosphorus? Calcium?

With that said, how does light does a Superman *Montipora* require? Instead of saying 'not much' or 'a lot', we can estimate the light requirements via the technique of non-invasive fluorometry. What does that mean? It simply means that we can, with proper instrumentation, observe how energy flows in the photosynthetic process. This energy flow is called the 'Electron Transport Rate' (or ETR for short). The higher the ETR, the higher the rate of photosynthesis. Here, we report 'relative ETR' (rETR) since absorption of light by photopigments within zooxanthellae was not measured.

It is a common misconception that reef aquaria cannot have too much light. To the contrary, evidence suggests many corals actually photo-saturate (where the rate of photosynthesis - the rETR - does not increase with increasing light intensity. For examples, see Ulstrap et al., 2006, where the SPS coral *Pocillopora damicornis* becomes photo-inhibited at ~450 µmol·m²·sec).

Photoinhibition is possible. Photoinhibition is the phenomenon of reduced photosynthesis where available light exceeds that needed for maximum photosynthesis. In these cases, zooxanthellae are trying to protect themselves from photo-destruction via dumping excess energy as chlorophyll fluorescence in a process called photochemical quenching. In addition, xanthophyll pigments within zooxanthellae can absorb blue light and dissipate this energy as non-radiant heat that is called non-photochemical quenching. So, what amount of light is sufficient for growth and coloration of the Superman coral?

Figure 2 demonstrates the rate of photosynthesis of one Superman specimen under various light intensities. For those arguing that these numbers represent only a snapshot of one coral's zooxanthellae after photoacclimation (which, of course, they do), I suggest that they've missed the point! The point is not so much that these rETRs are representative of zooxanthellae photosynthetic activity after photoacclimation to a given amount of light - it is the fact that the zooxanthellae have the ability to adapt to this particular amount of light!

If we assume that calcification rates are linked to rates of photosynthesis, then Figure 2 takes on added meaning. Examination of Figure 2 suggests photosynthesis (and hence calcification and growth) would theoretically be about the same at 250 µmol·m²·sec and 500 µmol·m²·sec. However, bleaching of a Superman specimen has been noted at a light intensity of only 300 µmol·m²·sec (and a photoperiod of 11 hours. It seems certain that light - and not temperature, ultraviolet radiation, or any other 'nasty' factor - is responsible for the bleaching. This observation certainly deserves further investigation).

The bottom line - analyses suggest these two *M. danae* specimens and their zooxanthellae seem to prefer lower light conditions, where intensity is only 100 - 200 µmol·m²·sec.

Known Symbionts

Recent 'fingerprinting' of zooxanthellae DNA has revealed a large number of sub-species or 'clades'. There are several known 'types' of zooxanthellae found in *Montipora danae,* including Clade C2 (based on ITS2 analyses, Van Oppen, 2004; 2005), C31 (LaJeunesse, 2004; Okinawa, Japan, 1-10m), C+ and C· (ITS1; Van Oppen, 2004).

Clade C2: This zooxanthellae clade is found largely in Family Acroporidae corals (*Acropora, Montipora,* among others) including *Acropora aspera, Acropora cerealis* (GBR, Van Oppen, 2001), *Acropora cervicornis* (Caribbean 2.0-17.0m, Baker et al., 1997), *Acropora cuneata* (Van Oppen et al., 2005), *Acropora florida, Acropora gemmifera, Acropora intermedia, Acropora longicyathus, Acropora loripes, Acropora millepora, Acropora nastua, Acropora spathulata, Acropora tenuis, Acropora valida* (GBR, Van Oppen, 2001),*Montipora aequituberculata, Montipora capricornis, Montipora danae, Montipora florida* (from Indonesia, Van Oppen, 2005 based on ITS2 fingerprint). Clade C2 has also been reported from *Pavona varians* (Van Oppen, 2005), *Goniastrea rectiformis* (Van Oppen, 2005), zooxanthellae collected and cultured from the clam *Hippopus* (LaJeunesse, 2003), and *Pocillopora damicornis* (two locations in Taiwan, 0-5.0m, Chen et al., 2005). C2 is believed to have adaptively radiated from Clade C3 (a 'generalist' zooxanthella).

It is an interesting notion that corals containing Clade C2 could possibly have the same range of photoacclimation. Photoacclimation in most zooxanthellae is not infinite in range, although it seems certain that some 'types' of *Symbiodinium* have more latitude in adjusting to light intensity than others. This is an important concept - zonation of certain corals has been linked to light intensity (Iglesias-Prieto et al., 2003), though factors such as temperature tolerance and others also play roles.

Clade C31: So far, Clade C31 seems to be most common in *Montipora* specimens. It has been found in *Montipora danae* specimens (Okinawa, Japan, 1-10m; LaJeunesse, 2004) as well as *Montipora* species (western and Central Pacific 2-20m; LaJeunesse et. al., 2003); *Montipora capitata* (Hawaii, 1-5m, LaJeunesse, 2004) and *Montipora patula* (Hawaii, 20m, LaJeunesse, 2004). C31 is believed to have evolved from Clade C21. Clade C31 has also been found in *Montastraea annularis* (Belize, 8m; Warner et al., 2006).

A pulse amplitude modulation (PAM) analysis of photosynthetic capacity of a shallow-water Hawaiian *Montipora capitata* (believed to contain Clade 31) found onset of photosaturation at ~135 µmol photons·m²·sec (~6,750 lux). Photoinhibition is thought to occur at ~250 µmol photons·m²·sec (Riddle, in press).

Based on the information about coral species and associated depth presented by researchers (above), it appears that Clade C31 zooxanthellae probably tolerate, if not prefer, lower light intensity.

Clade C+: Isolated from the Pacific stony coral *Montipora danae* (van Oppen 2004) in combination with Clade C2 (Van Oppen, 2004) and *Plesiastrea verispora* (Magalon et al., 2007).

Clade C·: This zooxanthella is believed to have co-evolved with *Montipora* species, but sometimes found in *Porites attenuata* and *Porites cylindrica*. *Montipora* species containing Clade C· include *Montipora aequituberculata, M. altasepta, M. angulata, M. cactus, M. capitata, M. crassituberculata, M. danae, M. delicatula, M. digitata, M. gaimardi, M. hispida, M. hoffmeisteri, M. mollis, M. peltiformis, M. spongodes, M. stellata, M. turtlensis, M. undata,* and *M. verrucosa* (van Oppen et al., 2004). This clade is presently known to be distributed from Indonesia southward to the Great Barrier Reef. One has to wonder if this clade has high fidelity to *Montipora* spp. and is one of those listed in LaJeunesse's more-or-less concurrent paper (namely Clades C17, C26a, C27, C30, C31, C31a, C31b, C32, C58 and C73). Van Oppen's IDs are based on ITS1 sequences (while LaJeunesse's - and many others'- are based on ITS2 fingerprinting).

Possibilities of 'Symbiont Shuffling'

Are the clades listed above the only zooxanthellae inhabiting *Montipora danae*? Probably not. But it is the best information currently available; however, new laboratory techniques will undoubtedly change our view.

Warming of the earth's oceans has generated much interest in how corals and their zooxanthellae respond to environmental conditions. Researchers are identifying the possibility of 'symbiont shuffling' where one zooxanthella clade loses its dominance due to unfavorable conditions (excess light, UV, temperature, etc.) and is replaced by a second clade that finds the new environment as hospitable and thus becomes dominant.

Much of the recent research work involves techniques that cannot detect zooxanthellae populations when they are less than 5-10% of the total population (although Mieog et al., 2007, report a technique with 100-fold increased sensitivity. Future results using this technique should prove quite interesting). Only one case to my knowledge demonstrates two clades living simultaneously in a *M. danae* specimen (C2 and C+; Van Oppen, 2004).

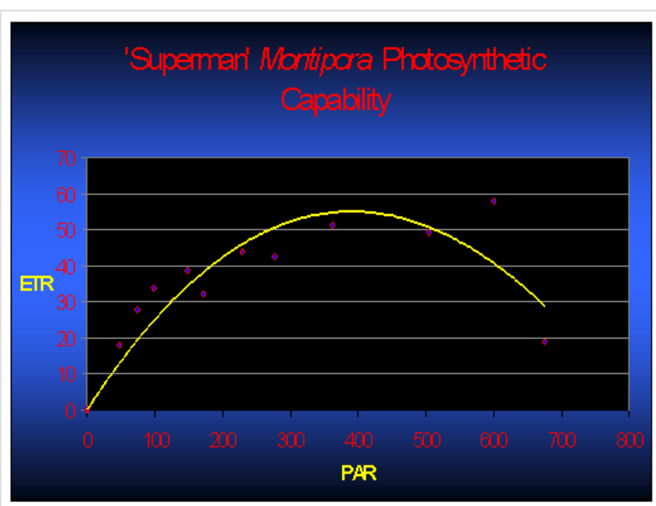

Figure 2. Photosynthetic activity (relative Electron Transport Rate, or rETR shown by the yellow line) of one Superman Montipora specimen. In this case, maximum photosynthesis occurs at a PAR value of ~400 μmol·m²·sec. Increasing light intensity above this point is counter-productive as photoinhibition occurs (as indicated by reduced rETR).

Zooxanthellae inhabiting *Montipora* specimens likely have a high fidelity for their host (and vice versa); In fact some clades are believed to have co-evolved with their host coral. In addition, *Montipora* larvae acquire their symbionts directly from the parental colony - the eggs are infected by zooxanthellae from the parent - in a process called maternal acquisition (not all corals behave in this manner - many larvae obtain symbionts from the water column). In either case, acroporid corals seem to have a preference for specific zooxanthella clade(s) (van Oppen, 2004).

Coral Pigmentation - What Color Do You Desire?

Coloration of the Superman coral is dependent upon the type of light and here's why: Analyses of fluorescence have revealed the presence of at least six pigments within the Superman *Montipora*. The major pigment is found within coral tissues and fluoresces at a peak of 489nm (blue-green). Their reddish color of the polyps is due to fluorescence peaking at 611nm (see Figure 6). Other minor fluorescent pigments are seen at 546, 567, 587, and 617, with possible fluorescent spikes at 491, 520 and 540nm. There is also an unidentified non-fluorescent chromoprotein at can make the coral appear blue or purple (depending upon the spectrum of the illumination source).

Note that other *M. danae* specimens can contain different pigments. For instance, Salih et al. (2006) identified two additional fluorescent pigments. Fluorescent emissions are seen at 483 and 495nm. Excitation wavelengths include UV-A, violet and blue wavelengths (see Figure 7).

Figure 7 is useful in understanding which wavelengths will make this coral fluoresce in the blue-green range. Although ultraviolet light will induce fluorescence, the maximum excitation wavelength is in the violet portion of the spectrum.

The purple chromoprotein seems to be expressed as a result of light intensity (although other 'proper' conditions in aquaria are also required). At light intensity of about 100 μmol·m²·sec, the purple coloration is barely seen, but growth is good (see Figure

Figure 3. Appearance of the Superman Montipora when illuminated by a warm-white fluorescent lamp. The non-fluorescent chromoprotein reflects blue and red light, making the coral appear violet/purple.

4). The bluish chromoprotein can become the apparent dominant pigment at ~175 µmol·m²·sec.

While non-fluorescent coloration seems dependent upon light, the fluorescent orange seen in the polyps and the blue-green 'body' pigments (produced by the coral animal and not zooxanthellae) are usually seem except when the light intensity is too high (and the coral bleaches) or when light is too low (and the zooxanthellae/host suffer from light deprivation. Though strictly speculation on my part, the host probably stops producing pigments as an energy-saving measure).

Figure 4. The same coral in Figure 3. Note the considerable growth that has occurred over 4 months time under 'low light' conditions - only 100 µmol·m²·sec, although much of the non-fluorescent purple coloration has disappeared.

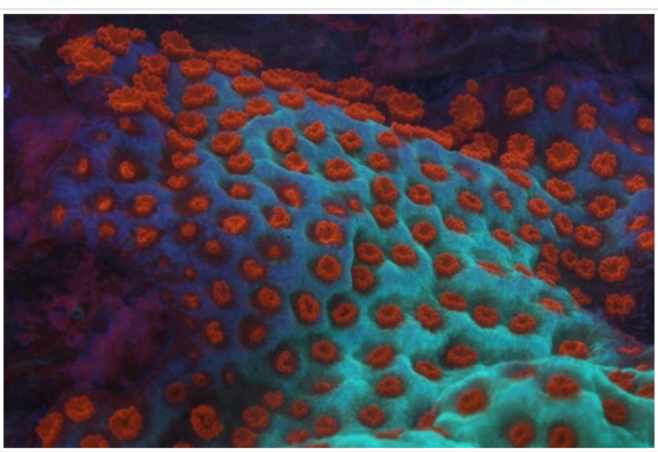

Figure 5. A closer view of the coral pictured in Figures 3 and 4. A high kelvin lamp will showcase the blue, green and orange fluorescent pigments.

Water Motion

This coral's 'bumpy' surface (called tuberculae or verrucae, depending upon their size relative to corallites) indicates this animal requires 'good' water flow. These tuberculae act as 'speed bumps' to laminar water flow and create turbulence, which is not surprising as these corals are often found on upper reef slopes. Slowing of water velocity by these bumps prevents deformation of polyp shape and allows the coral to feed.

Fortunately, creating sufficient water movement is quite easy with some of the newer propeller pumps and other devices (see Riddle, 2007).

Other Aquarium Conditions

The Superman *Montipora* fares well when other physical and chemical conditions in an aquarium are within 'reasonable' ranges. To avoid potential overheating of coral specimens, water temperature should not exceed 80° F when using metal halide lamps (see Riddle, 2006 for details). Although a link to coloration in aquaria conditions needs to be established, alkalinity and its potential relationship to coral tissue pH (Battad et al., 2007) under lighted conditions could also play a role in coral coloration.

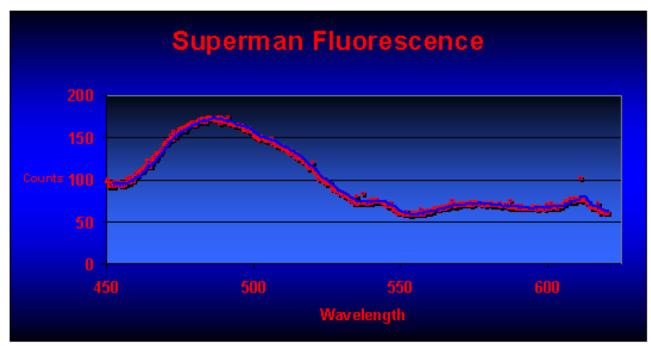

Figure 6. Fluorescent emission of a Superman coral reveals a major peak at 489nm. The reddish polyps fluoresce strongly at 611nm.

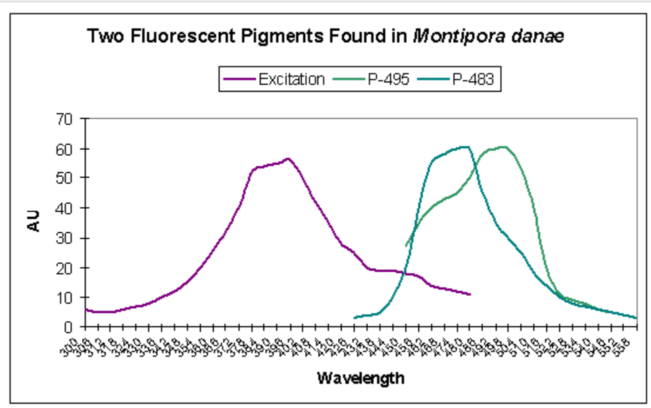

Figure 7. Two other fluorescent pigments from a Montipora danae specimen. After Salih et al., 2006.

Methods and Materials

Rates of photosynthesis were determined with a Walz 'Teaching PAM' Chlorophyll Fluorometer (Effeltrich, Germany) equipped with a fiber optic cord. A fluorometer is basically a 'photosynthesis meter' and exploits measurements of chlorophyll fluorescence in order to determine rates of photosynthesis (in terms of 'relative electron transport rate' or rETR between Photosystem I and Photosystem II within zooxanthellae. Since pigment absorption of light was not measured, the ETR is considered to be relative). Corals were maintained in total darkness for at least one hour before initial measurements were made in order to allow Photosystem reaction centers to 'open'. The external actinic light source was a 400-watt Iwasaki 6,500K metal halide lamp that was shielded for ultraviolet radiation by a clear acrylic material. Intensity was adjusted upwards by moving the light source closer to the coral (which was contained in a 3-gallon plastic container). Light intensity (Photosynthetically Active Radiation, or PAR) was measured with an Apogee QMSS quantum meter and a submersible, cosine-corrected sensor. Water motion was provided by a magnetic stirrer and a 3" stir bar.

After the dark-adaptation period, minimum chlorophyll fluorescence (Fo) was determined with weak light (<1 µmol·m²·sec) generated by the instrument's internal actinic lamp. Increasing the intensity of the internal actinic lamp to provide a saturating light pulse determined Maximum Fluorescence (Fm). The metal halide lamp was then turned on and allowed to warm up until PAR values stabilized (15-20 minutes). Chlorophyll fluorescence values were determined and the light intensity increased. The coral's zooxanthellae were allowed to adjust to the new light intensity for 15 minutes and another chlorophyll fluorescence measurement was made. The PAM meter calculated Photosynthetic Yield, which was simply multiplied by the appropriate PAR measurement in order to estimate the 'relative Electron Transport Rate' or rETR. This is a valid method for observing photosynthetic trends.

Fluorescence was determined with an Ocean Optics USB-2000-FL fiber optic spectrometer (Dunedin, Florida) using an 18-watt black light (maximum emission at 365nm) as the excitation source. Light was collected with a cosine-corrected CC-3 lens.

Photographs were taken with a Canon Rebel XTi digital camera (10.1 megapixels) equipped with two stacked teleconverters and a 60mm macro lens.

Comments on Basis of Identification

Veron (2000) states: "The identification of aquarium-raised corals is a difficult and sometimes impossible task... They may also assume growth forms which are sometimes seen in the wild, but usually only in deep water that may be unusual for the species." With that said, hobbyists are cautioned that information contained within this article was obtained from two aquarium-grown specimens, and, although best efforts have been made to identify these animals, limitations of the software lend a degree of uncertainly as to the exact coral species.

In an effort to identify these corals, twenty-seven identification points, including those observed from two living and one skeletal remains, were entered into Veron's *Coral ID* software. These observations for data entry were made from examinations of enlarged photographs of living corals and microscopic examinations of a skeleton.

To properly identify a coral, its geographic origin should be known, and in these cases, the collection point(s) is not known. Assuming these corals originated from the central Indo-Pacific Ocean (including Indonesia, Philippines and Solomon Islands), the software determined identity as *Montipora danae* or *M. undata*, with the software's 'Best Bet' option signaling *M. danae* as the proper identification.

While changing the location data point (and retaining all others), the identification consistently included *M. danae*. For instance, entering Oceanic West Pacific (including Fiji) the software also returned two possibilities - *Montipora danae* and *M. undata.* Similar results were listed for SW Indian Ocean. Central Pacific (including Tonga) suggested only one possibility - *M. danae*.

These are the other identification criteria (those items in italics were determined by microscopic exams):

- Multiple mouths and corallites
- Attached to the substrate (as opposed to free-living)
- Hemispherical, sub-massive or encrusting growth forms
- Branching absent
- Calice width less than 1mm
- Corallite centers distinct
- Corallites separate individuals
- Immersed corallites
- Neither axial nor central corallite
- Corallites widely spaced (more than twice the diameter of the corallite opening)
- Tentacles expanded by day
- Tentacle length <10mm
- Partial skeletal masking

Figure 8. Distinctly different skeletal growth forms within millimeters of each other. To the right, linear elaborations typical of many Montipora specimens are dominant. To the left, the skeleton flattens to a rather featureless, flattened growth pattern.

- Daytime tissue projection <1mm
- Extra-thecal skeleton present
- Extra-thecal surface perforated
- Linear elaborations present
- Linear elaborations greater than calice diameter
- *Columella absent*
- *Costae absent*
- *Septa not fused*
- *2 cycles septa*
- *Septa not exsert*
- *Septal margin not smooth*
- *Paliform structures absent*

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FEATURE ARTICLE

ALGAE: SOMETIMES BOTH BEAUTIFUL AND USEFUL

By Christopher Paparo

Too often marine macro algae are only considered to be part of an aquarium's filtration system.

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Just the mere mention of the word algae in a room of aquarists will send them running for their scrub pads. Algae are the nemesis of most aquarists, from pesky diatom algae covering our décor in a brown film, to the nearly impossible to eradicate hair algae. Not all algae should be despised however; many types are extremely useful and some can be quite beautiful.

Most of us are familiar with the ornamental species common to the trade, such as *Caulerpa* and *Chaetomorpha*. Occasionally species of *Codium, Halimeda, Acetabularia,* and some miscellaneous red species will show up at your local fish shop attached to a piece of base rock. But how many of us have wandered the local shoreline in search of algae for our aquariums?

Living on Long Island, I am fortunate to be minutes away from the bay or ocean. A short walk along the shoreline at low tide will expose you to a wide variety of algae. Many of the species, being temperate in range, will tolerate a wide range of temperatures, including those of a reef environment. Knowing what to look for will enable you to collect algae for your home aquarium.

There are three phyla of algae; Chlorophyta (green), Chrysophyta (brown) and Rhodophyta (red). Each of these phyla has unique characteristics causing them to be found at different depths of the water column.

Chlorophyta, the green algae, need more light than the other phyla and will be found higher in the water column. Of the greens, *Ulva lactuca*, or better known as sea lettuce, is probably the most abundant and widely known. Growing in large, thin sheets, it is unmistakable. Ranging from subarctic to tropical environments world wide, it can be found growing among the rocks of an inlet, to the calm waters of the back bay. It is frequently found thriving in areas of high nutrients.

A species similar to *Ulva lactuca* is *Ulva intestinalis* (formerly, *Enteromorpha intestinalis*). This green alga shares the same environment as *Ulva lactuca* but grows in long narrow tubes. This growth form allows it to survive in areas that might be too turbulent for the delicate sheets of *U. lactuca* to grow. As with many plants and even some animals (i.e., corals), morphology will vary with environmental conditions. In areas of high current or wave action, it tends to grow in very narrow tubes, almost as if it was hair algae, while growing in wider tubes in calm conditions. Large blades growing in such a turbulent area would only be broken off before the alga gets a chance to grow. Like *U. lactuca*, *U. intestinalis* has a worldwide range.

Arriving to the east coast of America from the Pacific in 1957, *Codium fragile* is an invasive green alga that is quite abundant. Commonly called Dead Man's Fingers or Green Fleece, *C.fragile* grows in ropelike spongy branches, and when exposed at low tide, it looks like fingers. *C.fragile* is unique as it is a long single cell that is made up of many nuclei but no cell wall dividing them. Being able to reproduce by fragmentation has allowed it to spread

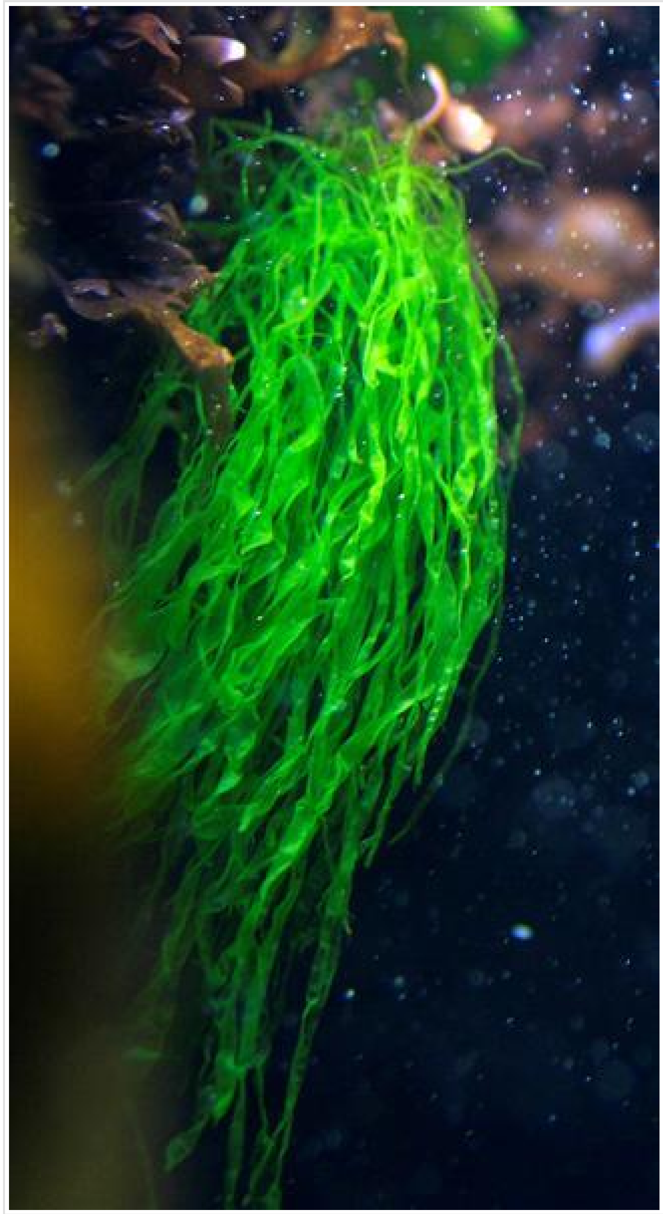
Rocky intertidal zone at Orient Point, NY

easily through out the east coast of North America. This invasive species has been very destructive to shellfish beds, especially oysters. Upon attaching to a shellfish, wave action causes the shellfish to be "uprooted" and the currents wash it ashore. This species is commonly found in calm, protected waters. Locally, I tend to find it attached to some of our more common epibenthic mollusks such as Cockles and Slipper Shells.

Chrysophyta, the brown algae, tend to grow much larger than the greens. Some of The most common brown algae of the inter-tidal zone belong to the genus, *Fucus*. Fucus can tolerate exposure to a wide range of environmental conditions. Being exposed at low tide, it is subject to freezing in winter months, and to extreme heat and dehydration in the summer. To adapt to these harsh conditions, *Fucus* has thick rubbery blades allowing the algae to retain moisture while it is exposed. The blades of *Fucus* have many air bladders that provide buoyancy for the blades. This buoyancy allows the blades to sway in the currents removing any detritus that has settled during the low tide. Algae growing in high surge areas will have fewer bladders as the current will keep the blades moving. Growing mostly in cooler waters, it has a worldwide distribution.

Ulva lactuca

Another type of brown algae found on our shorelines is kelp. When talking about kelp, we think of the giant kelp forests of cold-temperate waters such as the California coast, New England, and western South America. Some species, such as *Macrocystis pyrifera*, can grow at a rate of 30 cm a day and can reach a length of 60 meters. Like *Fucus*, giant kelp has air bladders that keep it suspended in the water column. On the east coast of North America, our species of kelp, *Laminaria agardhii,* is much different than *M.pyrifera.* Under ideal conditions, it can grow 2 cm a day, growing to 3 meters in length. Looking like a large lasagna noodle, it has one large blade, a stipe (similar to a stem), and a large holdfast. Similar in appearance to roots of vascular plants, the holdfast's sole purpose is for attachment, there is no nutrient uptake. Growing in areas of strong surges, the holdfast is important to keeping the alga from washing away. Unlike *M.pyrifera, L.agardhii* has no air bladders. It depends on strong currents to keep it suspended in the water column. Long Island is the



Ulva intestinalis

southern most part of *Laminaria's* range, and can only be found in the winter months.

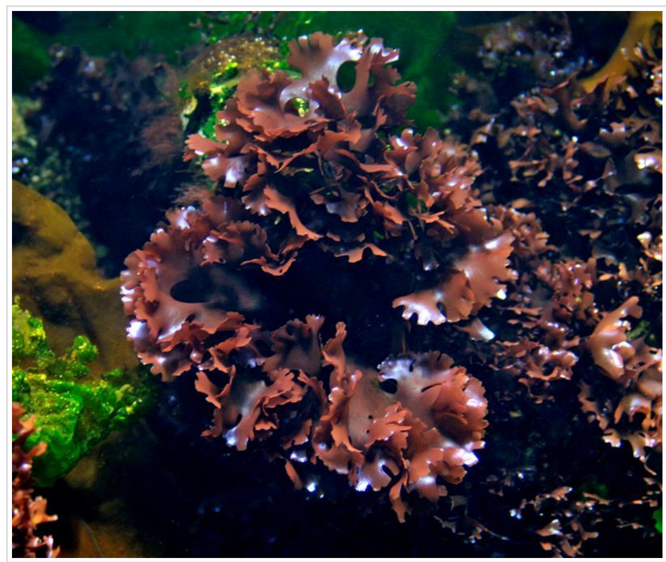
The last group of algae you will find while walking the beach are the Rhodophyta or red algae. Red algae contain a pigment called phycoerythrin. This pigment absorbs blue light and reflects red light, giving the algae its red color. Being that blue light penetrates deeper in the water column, red algae tend to be found growing at greater depths. This can make it a little more difficult to collect as you might need to get your feet wet to find a suitable specimen. An abundant and well-known red seaweed in our local waters is *Chondrus chrispus*, better know as Irish

Codium fragile with a red algae growing as an epiphyte.

Fucus sp.

Laminaria agardhii

The holdfast of Laminaria.



Chondrus chrispus

Agardhiella tenera

Moss. *C.chrispus* is commercially harvested for use in the food industry. Carrageen is an extract of *Chondrus* that is used as a thickener in soups and dairy products.

This is the macro algae tank I care for at Atlantis Marine World and will go into more detail on the care of such a tank in a future article.

One red algae, although not a macro algae, is encrusting coralline algae. Common to the tropics, encrusting coralline algae is absent from Long Island waters. As you move north away from Long Island, encrusting coralline algae becomes common once again. Even though encrusting red corallines are absent, we do have a macro coralline alga, *Corallina officinalis*, better know as coral weed. Unlike the encrusting species, it grows as fan-like tuffs reaching only a couple inches in length. When found washed up on the beach, it is white in color and will crumble in you hand when you pick it up.

Two other species of red algae commonly found around Long Island and ranging to the tropics are, *Agardhiella tenera* and *Gracilaria foliifera.* Both species are delicately branched and their color can vary from a bright red to almost brown. They can be found attached to rocks or shells, but are more commonly found free floating. They seem to prefer calm waters where they are less likely to be washed ashore.

Too often marine macro algae are only considered to be part of an aquarium's filtration system. They are tucked deeply away in a refugium under ones aquarium, never to be shown as proudly as the main tank. Many of these algae are extremely beautiful, and deserve their own display. Although they do pose some challenges in keeping them, it can be done and I will share with you how to keep them in a future article.

FEATURE ARTICLE

West Atlantic Stony Corals Part 2: SPS Corals Continued and *Faviid* Corals

By Jake Adams

Jake continues his series on Atlantic stony corals.

Published February 2008, Advanced Aquarist's Online Magazine.

Keywords (AdvancedAquarist.com Search Enabled): Atlantic, Coral, Feature Article, Jake Adams
Link to original article: http://www.advancedaquarist.com/2008/2/aafeature4

Siderastrea is a genus of small polyped stony corals which is also known as starlet coral. The three species are most often colored pale to dark brown but they can be vivid pink or blue in shallow water. In ideal reef conditions *Siderastrea siderea* commonly grows to two feet in diameter and it sometimes grows to twice that size. The genus grows into massive, encrusting or hemispherical shapes.

S. radians is the most durable Siderea species and it perhaps the most extreme stony coral in the Atlantic Ocean. It is the only coral which can be found growing high in the littoral zone, in inter-tidal pools which can experience very high temperatures. Although these colonies are pale and stunted, they still occur at great abundance in these stressful environments. In shallow water, *S. radians* is mostly brown but it can be difficult to distinguish from the similar yet slightly smaller polyp *S. siderea*. *S. radians* is frequently brought into the aquarium trade on Florida aquacultured live rock.

The reef scene depicts four West Atlantic coral species which are covered in this article: Siderastrea siderea at left, Diploria labyrinthiformis in the middle, Montastrea annularis at right and Diploria strigosa at bottom center. Aldo Croquer.

S. stellata are typically smaller encrusting or hemispherical colonies which occur at intermediate depth. The species has the larger, more recessed corallites of the *Siderea* species. The corallites

The inch-long neon gobies are frequently seen perching on Siderastrea siderea colonies.

Siderastrea radians has a pitted, uneventful surface.

have a polygonal shape with bright corallite walls, giving the coral a noticeable honeycomb pattern. The species is rarely very large and not very abundant.

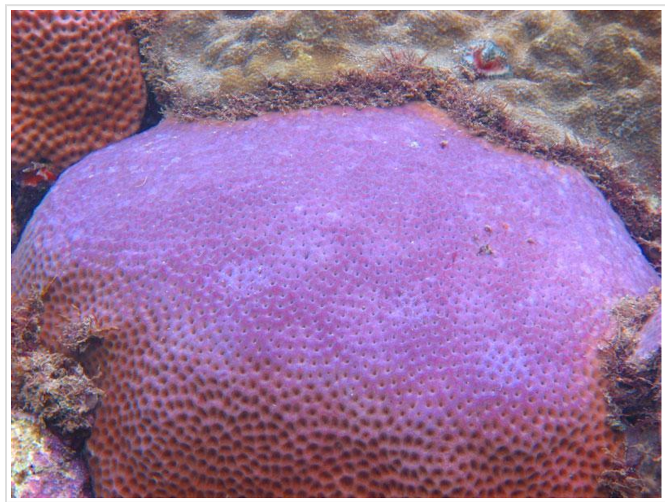
S. siderea is largest and most abundant member of the genus. It is more common in shallow water where it will be encrusting to submassive when small and hemispherical when it is large. In some environments it will often develop a brilliant pink or blue color, especially on the side which is receiving the most light. The corallites of *S. siderea* are of intermediate size for the genus, they are slightly recessed and they appear as little pits on the surface of the colony.

Madracis occurs in both the Atlantic and Pacific Oceans and it is represented in the tropical West Atlantic by no fewer than five species. The *Madracis* genus belongs to the Pocilloporid family which makes it closely related to familiar aquarium corals such as *Stylophora* and *Seriatopora*. Like its Pacific counterparts *Madracis* grows into various branching shapes but there are also a few species which are cryptic and encrusting. The polyps are very small and often extended during the day, giving *Madracis* species a fuzzy appearance.

M. mirabilis grows into thin, pale yellow branches which is why it is called yellow pencil coral. In its marginal, deepwater habitat *M. mirabilis* occurs as small isolated patches but it is most abundant in shallow water where it forms large, sometimes extensive monotypic stands. The open nature of the skeleton provides refuge for a host of cryptic and commensal creatures which densely colonize *M. mirabilis* colonies, leaving just a few inches of living tissue at the tips.

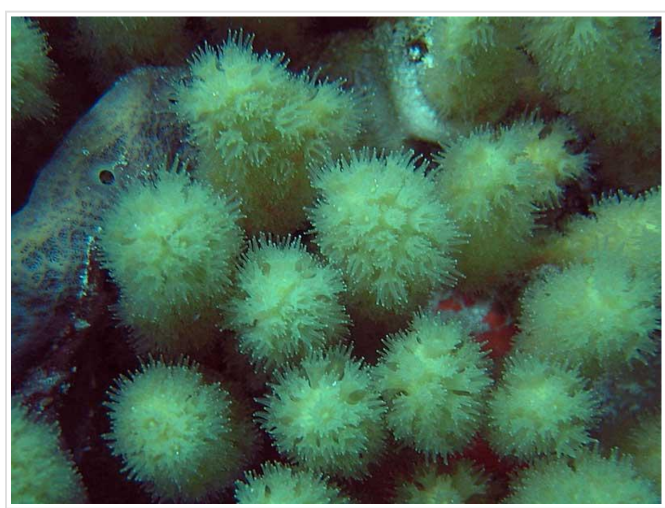
M. decactis and *M. formosa* are corals with very similar growth forms but they are identified by minute skeletal features. *M. decactis* is paler in color, usually olive or tan, with short bulbous branches and ten primary septa visible in the corallites. *M. formosa* is darker in color, often dark brown with pale corallite centers and eight primary septa visible in the corallites. *M. formosa* colonies are also larger with broad, slightly flattened

Siderea stellata has a unique honeycomb appearance



When growing in shallow water Siderastrea siderea can develop very brilliant coloration.

Under ideal reef conditions Siderastrea siderea can grow to massive sizes. This large spherical colony was over four feet in diameter.



The extended polyps of this Madracis mirabilis make it appear fuzzy. Nate Kwiatek.

branches. Both species co-occur at intermediate to great depths but *M. decactis* is generally more common than *M. formosa*.

Faviids

Favia fragum is a fast growing yet short-lived coral species. The brown, tan or orange colonies are crustose or hemispherical and they rarely grow much larger than a couple of inches across. The polyp mouth is recessed into the skeleton but the corallite itself can be exert from the surrounding skeleton. *F. fragum* goes by the name of golf ball coral and it is can sometimes found growing on Florida aquacultured rock. It can be found in shallow water habitats above about twenty feet and it is particularly abundant in backreefs and other environments with slightly reduced wave action. This coral can resemble small colonies of *Dichocoenia stokesi* but that species has much more exert corallites and more noticeable septa around the corallite walls.

Colpolphyllia natans grows to the largest size of all massive corals in the tropical West Atlantic Ocean. *C. natans* commonly grows to over six feet across with some of the largest individuals reaching twice that size. The surface of the coral colony has wide meandering grooves with darker colored ridges. The skeleton is so

The branches of Madracis formosa have somewhat flattened ends.

Madracis mirabilis can form extensive stands in shallow water. Nate Kwiatek.

Favia fragum rarely grows much larger than the size of the pictured specimen.

Madracis decactis has somewhat bulbous branch tips.

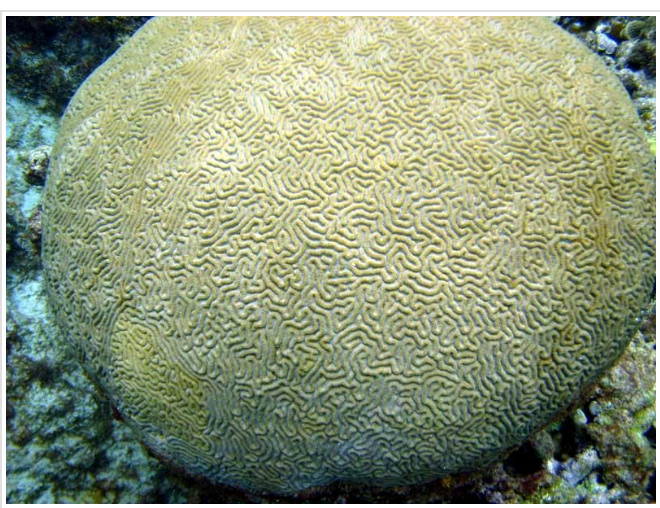
This C. natans has a striking pattern.

porous that it can float once dried out which has led to some archeological confusion in the past when specimens of this species were found far from any modern tropical coral reefs (Korniker and Squires 1962). This genus is one which was found to have a significant enough divergence from the Faviid family lineage to suggest being placed in a separate family (Fukami et al 2006).

Diploria is an abundant and important reef-building coral genus on West Atlantic reefs. The genus contains only three species which grow into diverse forms but they are easily distinguished based on the size and density of their grooves. Ancient *Diploria* fossil skeletons are the source of the famous Florida Keystone. The three species of *Diplora* co-occur together in all environments but they have separate peaks of abundance based on depth. The long continuous valleys of *Diploria* species most resemble *Leptoria* and Australian *Goniastrea* species which are available in the aquarium trade,

D. clivosa is the least common of the *Diploria* species. It is only found in shallow water habitats above fifteen feet where there is

C. natans sometimes has exceptionally brilliant color.



In shallow, high energy reef environments, D. strigosa often grows into a spherical shape.

a generous amount of water motion. The color is usually pale brown or olive but very occasionally it can have brilliant green grooves with contrasting dark brown ridges. *D. clivosa* colonies grow encrusting or hemispherical shapes with small, tightly meandering grooves and a knobby irregular surface.

D. labyrinthiformis is a very fleshy species with deep meandering corallite valleys. The width of the corallite valleys varies greatly between specimens but the species is easily recognized by the presence of a noticeable groove on the ridge between the valleys. Even during the day the polyp tentacles are often visible protruding slightly through the narrow valleys. *C. labyrinthiformis* most often grows into hemispherical shapes on the seaward part of reefs. Although the species can occur at all but the shallowest depths, it is most abundant *Diploria* species on intermediate to deeper reefs. Colors of *D. labyrinthiformis* are most often pale tan, grey or olive with the occasional specimen being pastel yellow or green.

The common appearance of the narrow-grooved D. clivosa growing in shallow water.

This is an exceptionally brilliant specimen of D. clivosa growing at about 15 feet deep.

This image taken in shallow water shows D. labyrinthiformis on the left and D. clivosa on the right.

This specimen of D. labyrinthiformis has particularly wide grooves.

An exceptionally large D. labyrinthiformis growing at intermediate depth. Aldo Croquer.

D. strigosa is the most common *Diploria* species on many West Atlantic reef habitats. The species is frequently a dominant coral of shallow water reefs where large hemispherical colonies often grow to over three feet in diameter. The meandering continuous corallite valleys are regular in appearance and evenly spaced. Corallite valleys are mostly perpendicular to the colony edge, often with brightly colored grooves which contrast with the darker colored ridges. *D. strigosa* is a frequent host of *Spirobranchus* featherduster worms and some older colonies become veritable featherduster condominiums. The species is most abundant at shallow to intermediate depths.

Manicina areolata is a Faviid but because of the puffy appearance of the fleshy tissue it often resembles a Mussid. Although this species doesn't usually get much larger than a few inches across, in certain shallow backreef and lagoonal habitats it can occur at densities well above a dozen individuals per square meter. Juvenile *Manicina* corals begin life as a conical oval shaped polyp which is attached to a substrate by a central stalk. The most common *areolata* growth form has tighter valleys and it will maintain an elliptical outline with a conical base that can remain attached or

D. strigosa occasionally has beautiful blue meandering corallite valleys.

D. strigosa frequently hosts featherduster worms and old colonies may accumulate an abundance of them over time.

become free-living and lying in the substrate. The less common *mayori* growth form has wider valleys and it grows to a larger size with a flattened underside. Although nearly all Atlantic stony corals are unavailable in the aquarium trade, this species is an exception. *Manicina* frequently grows out on cultured live rock from the Tampa Bay area and it is available from dealers who request this coral along with their rock. The free living form of *Manicina* greatly resembles the common *Trachyphyllia* coral.

Montastrea is a prominent genus of Atlantic corals which also occurs in the Pacific Ocean. The genus is the second most important contributor to the reef building process after *Acropora*. The genus contains four recognized species although there is some evidence to suggest that the larger polyped *M. cavernosa* may comprise more than one species.

M. annularis is a fast growing coral which forms large aggregations of lobed colonies in shallow water. Although the individual lobes of *M. annularis* are usually no more five to six inches across, the aggregations may form large single species stands. In deeper water the lobes become cylindrical columns with live tissue mostly on the topside of the columns. The surface is relatively smooth overall with the color usually appearing tan, creamy brown or green. The species was long thought to contain three distinct growth forms but those have since become reclassified into three separate species. The small polyps of *Montastrea* species in the annularis complex can resemble the *Cyphastrea* species of the Pacific Ocean.

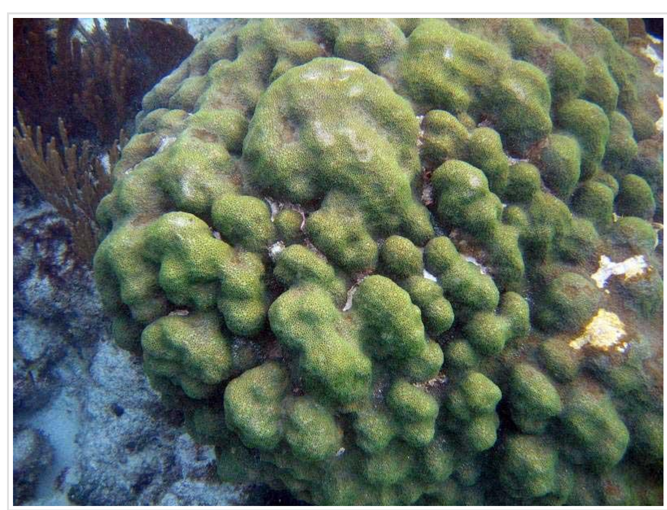
M. faveolata is a small polyped *Montastrea* which is common on a wide range of reef habitats but it is most abundant at intermediate depths. The colonies are encrusting or hemispherical when small becoming mound-shaped and plating at the edges when large. Huge, thousand year-old colonies can grow to over a dozen feet across. The surface is mostly smooth, appearing grey or tan, sometimes with bright green or yellow colored polyps.

M. franksi is the deepwater representative of the small polyped *Montastrea* species. *M franksi* usually grows encrusting, hemispherical or plating with a bumpy nodulous surface which is

This image taken in shallow water shows D. clivosa on the left and D. strigosa on the right.

An example of an individual lobe of M. annularis

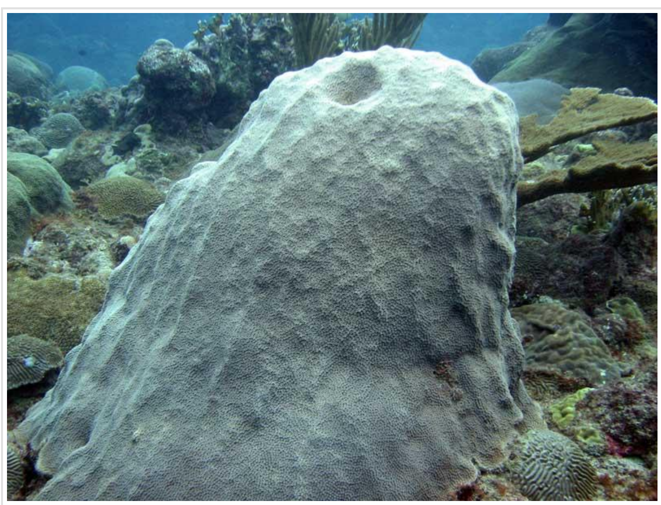
These Manicina were both brought into the trade on Florida aquacultured live rock.



A large colony of M. annularis growing in the shallow water of a wave-washed fore-reef

unlike any other *Montastrea* species. The tissue is pale brown or grey overall with irregular, lighter colored patches and orange to reddish polyps. *M. franksi* colonies do not grow to nearly the size of the other *Montastrea* species.

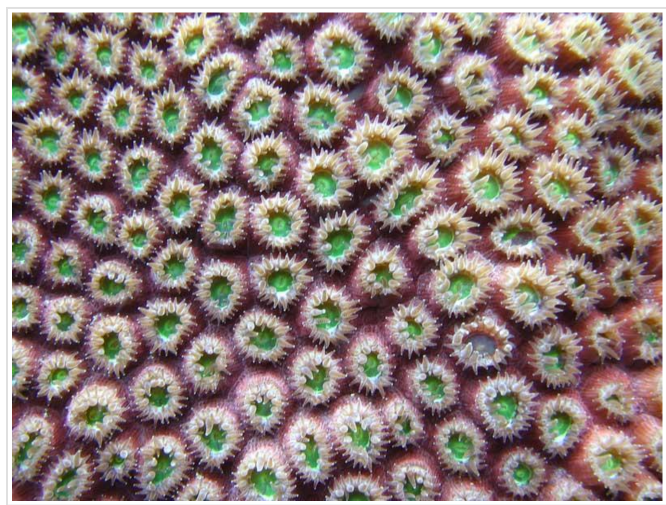
M. cavernosa is the large polyp representative of *Montastrea* in the Atlantic Ocean. The colonies grow into massive boulder or hemispherical shapes at intermediate, becoming increasingly plating with depth. *M. cavernosa* is a highly variable species which occurs in many colors including red, pink, brown and blueish with green, yellow or white polyp interiors. The corallites are strongly exerted from the surrounding skeleton with two distinct forms which have different abundance distributions separated by depth. The small polyped form has cone-shaped corallites, is more abundant in shallow water and it usually has polyps extended during the day. The larger polyp form has button shaped corallites, it is more abundant in deeper water and the polyps are rarely extended during the day. One morphological study found enough differences between the two forms which could not be explained by environmental factors to suggest further investigation into the taxonomic status of the species (Amaral 1994).



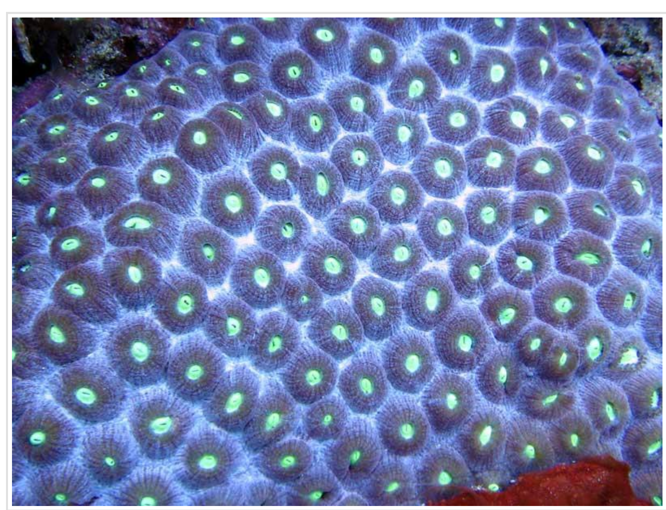
This huge mound of M. faveolata is not even close to the maximum size of M. faveolata.

A small isolated lobe of colorful M. faveolata.

The irregular surface of this coral identifies it as M. franksi.



Like most smaller polyped M. cavernosa, this coral has polyps extended during the day.



An abundance of speckling gave this M. cavernosa an overall blue-grey appearance.

The next article will conclude the coverage of West Atlantic corals with the large polyp stony corals and it will also cover the fire corals and some of the non-reefal corals.

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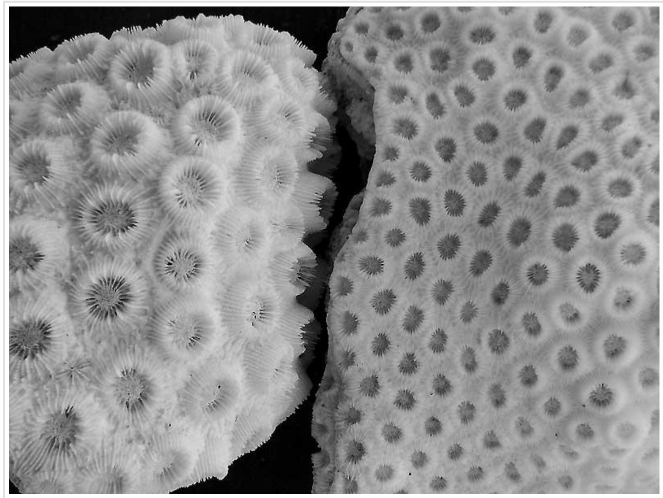
The red fluorescence of M. cavernosa was recently determined to be caused by symbiotic, nitrogen-fixing bacteria (Lesser et. Al 2004).



This image depicts the large difference in corallite size and spacing of the two supposed forms of M. cavernosa.

REEFKEEPING EVENTS

What's Happening in Your Area?

By Advanced Aquarist Readers

Check to see if an event is happening in your area!

Published February 2008, Advanced Aquarist's Online Magazine.

Keywords (AdvancedAquarist.com Search Enabled): Advanced Aquarist Readers, Reefkeeping Events
Link to original article: http://www.advancedaquarist.com/2008/2/events

Do you have an upcoming event?

If so, please email us at feedback@advancedaquarist.com and let us know about it!

2008 SouthWestern Coral Farmers Market Third Annual Event, February 24

Date: Sunday, February 24th, 2008
Time: 10:30 AM to 4 PM
Location: Hilton Ontario Airport Hotel, 700 North Haven Avenue, Ontario, California 91764
Website: http://www.sw-cfm.com/

This 2008 Coral Farmers Market sanctioned event is the third annual event run by the SouthWestern Coral Farmers Market company. We now have confirmed reservations for 35 coral farming and exhibiting vendors who will be selling or displaying their captive grown, cultured corals or reef related products to the public. This is scheduled to be the largest Coral Farmers Market event to date. This will also be one of the largest displays of the absolute best exotic captive grown corals ever presented to the buying public. We expect at least 400 total attendees.

Some of the best coral farming vendors from Southern California, the states of Utah, Nevada and Arizona along with farmers from the California Bay Area and Sacramento will be setting up coral displays. Farmers include aquarists, retail reef shops, online coral shops and full scale coral farming enterprises. There will also be exhibitors present who will be demonstrating and selling their products. This SW-CFM event will also feature coral auctions, raffles and door prizes throughout the day. Reef aquarists new to the captive reef market can also expect to see a fine collection of easy to keep beginner corals. For the first time in a Coral Farmers Market event we will also have a Marine Fish Hatchery company exhibiting and selling captive bred marine fish. Aquarists and enthusiasts can attend this one-day event by purchasing a SouthWestern Coral Farmers Market day ticket online for ($15) up to 4 weeks prior to the event. Within 4 weeks of the event the online ticket prices will be ($25). Tickets will also be sold at the door ($30) during the day of the event, but may be limited by occupancy restrictions. We are also encouraging our farmers to bring plently of farmed soft corals along with their usual excellent farmed stony corals.

The 24th Annual Raleigh Aquarium Society Workshop and Auction, February 29 - March 2

Dates: Friday, February 29th - Sunday, March 2, 2008
Location: NC State Centennial Campus, Engineering Building 1, 911 Partner's Way, Raleigh, NC 27606
Website: http://raleighaquariumsociety.org/main.html

Please note that this is a different location from years past. Here is the schedule:

Friday: The native fish collecting trip will be during the day and our Marine Aquarium presentations will be that night. So far we know we have Brian Plankis of Project DIBS speaking and we are in the process of confirming our second speaker. There will also likely be a frag swap and fragging demonstrations that night. More details will follow.

Saturday: Saturday will include several freshwater fish and plant presentations as well as some general presentations which pertain to both freshwater and marine aquaria. More details will follow.

Sunday: This is our annual auction of fish, plants, corals, inverts, dry goods, tanks, and anything else aquarium related. Anyone is welcome to buy or sell. A portion of all proceeds go to benefit The Raleigh Aquarium Society and costs related to the workshop.

If anyone has any questions about the Workshop, please feel free to e-mail carmiejo@hotmail.com or Ltwaddle@yahoo.com.

Marine Aquarium Expo, Saturday, April 5-6

The First Annual Marine Aquarium Expo (MAX) is a TWO DAY EVENT at the Orange County Fair & Exposition Center (Costa Mesa, CA) April 5-6 2008!

Dates and Times:

- Saturday, April 5th 12:00 noon to 8:00 PM
- Sunday, April 6th 10:00 AM to 6:00 PM
- Calendar Information

Event Information:

- Over 100 exhibitor's booths!
- Manufacturers, Wholesalers, Retailers, Exhibitors
- Livegoods/Drygoods for sale throughout the building
- 8 major Speakers lined up! (4 per day)
- Multiple Workshops and Demonstrations
- Children's Petting Pool and education area (pending)
- Frags! Frags! and more Frags! need I say more?

Admission: Adults $10.00, Seniors $5.00, Children 12 & under are Free!

MAX is held in Building #12, (22,000 sq. ft. fully-enclosed, air-conditioned exhibit hall). An adjoining 7,000 sq ft. covered courtyard will host much of the peripheral activities (speakers, workshops, raffles, seating area, etc.). This greatly enhances the space available inside building 12 for commerce. In other words: More room for everyone!

HUGE RAFFLE at the end of each day! Special Note: 50% of ALL Raffle Proceeds will go to 10 select public charities, all of whom are participating in MAX either directly or indirectly. (some represented by hobbyists doing a workshop on behalf of the charity)

This is a VERY family-oriented event, so please plan on bringing the entire family for a weekend of spectacular exhibits, speakers, workshops, displays, and other entertainment. Great food, clean restrooms, even a seating area.

Ladies and Gentlemen, this event is expected to attract over 3,000 hobbyist from all over the United States! Participating vendors and attendees alike are coming from all parts of the country. In fact, MAX is soon to become the largest event of its kind in the entire North American continent in terms of overall attendance. You don't want to miss this one!

For more information, visit us at: http://www.marineaquariumexpo.com

Contact Information:

Kevin T. Adams, MBA, Promoter
"Marine Aquarium Expo 2008"
8072 Central Avenue
Garden Grove, CA 92844
info@MarineAquariumExpo.com
(714) 530-1094 office
(714) 260-6660 cell

(please note: MAX is not affiliated with any club organization)

CTARS Marine Aquaium Conference, April 13

Date: April 13, 2008
Time: 9 AM - 5 PM
Location: Courtyard Marriott, 4 Sebethe Rd., Cromwell, CT
Website: http://www.ctars.org/default.aspx?uc=conference

Featuring:

- Adam Blundell
- Mystic Aquarium
- Joe Burger
- James Fartherree
- Huge Raffle
- Club Frag Swap
- Vendors

No tickets will be sold at the door.

14th Annual All Ohio Frag Swap, April 13

Sponsored by C-SEA

Date: Sunday, April 13th, 2008
Time: Noon to 4 pm, with HUGE raffle beginning at 3 pm
Location (same site as last year):
American Legion Hall, Clifton Post
22001 Brookpark Rd
Fairview Park, OH 44126

Directions are available at the C-SEA website: www.c-sea.org

Admission $5 per adult; under 14 yrs old is free.

- Admission gets you 4' of table space and 4 hours of frag swappin' madness!
- Electricity available (within reason--leave the 1000W MH at home please)
- Doors open to swappers at 12 noon
- Food available in attached restaurant and bar (we'll try to make sure the cook has more help this year!)
- Plenty of free parking.

And don't forget the dry goods raffle at the end of the swap! $1 per ticket; $5 for 6 tickets

More information to follow on attending vendors. The swap had over 350 attendees through the door last year. Lots of frags for sale/trade.

Midwest Frag Fest, May 3-4

Date: May 3-4, 2008
Time: Saturday (9 AM - 5 PM), Banquette @ 6 PM; Sunday (9 AM - 2 PM), raffle 3 PM
Location: Clock Tower Resort and Conference Center, 7801 E

State Street, Rockford, IL 61108-2721, US
Website: http://midwestfragfest.com/index.html

Midwest Frag Fest is the premier coral conference across the midwest. Frag Fest 2008 will be held on May 3rd and 4th at the Clock Tower Resort and Conference Center located just off of I-90 in Rockford IL. Our goal is not only to provide both hobbyists and vendors across the region with the best experience at an event of this type, but to donate a portion of the proceeds towards reef conservation and also give back to the community. Admission will be discounted with the donation of canned goods for a local food pantry.

Attendee information:

- Hotel accommodations are available at a reduced rate at the Clock Tower Resort for only $94 per night.
- Full event pass includes admission to all speakers, trade show and frag area, banquet dinner, and event T-shirt . The cost is $55. Sign up fast. First 40 to register will sit at a speakers table at the banquet. What a wonderful opportunity to chat with the pros
- One day pass with all access for that days events are available as follows:
  - Saturday with dinner $45
  - Saturday with out dinner $20
  - Sunday $20
  - Trade show, fragging area only $10
  - All at the door admissions reduced by $1 per can good donated up to $5 off

Speakers include Adam Blundell, Rod Buehler, James Fatherree, Mike Paletta, Gary Parr, Steven Pro, and Randy Reed.

International Marine Aquarium Conference '08, May 30-June 1

Just Imagine...a weekend where you can see live presentations by the most widely known, well-respected authors and lecturers in the marine aquarium hobby.

At the International Marine Aquarium Conference the speakers will be covering all the latest information and research on marine aquarium fish, corals and invertebrates. Meet with them socially, see exhibits by some of the foremost manufacturers and dealers in the aquarium hobby, and get some great deals on conference specials.

IMAC is open to ALL hobbyists . You do not have to belong to a marine aquarium society or even own a reef tank to attend, just be interested in learning more about this fascinating hobby. IMAC is a non-profit venture by hobbyists for hobbyists to insure the continuation of an annual educational event for aquarists, at a reasonable cost.

Whether you are a seasoned aquarist or just a beginner, IMAC is something you need to take in. And IMAC is put on each year by the same people, so if you attended IMAC in 2003, 2004, 2005, 2006 or 2007 you know the high quality of the show that we will put on.

IMAC 2008 will take place in Chicago, Illinois, USA - May 30, 31 and June 1 at the Crowne Plaza Hotel, Chicago IL:

Crowne Plaza Hotel, Chicago O'Hare
5440 North River Road
Rosemont, IL 60018, USA

For more information, visit http://theimac.org/ or contact Dennis Gallagher.

MACNA XX, September 5-7

Presented by Atlanta Reef Club and MASNA, MACNA is the largest hobbyist marine conference in North America. New aquarium products, vendors will often wait until MACNA to release new products into the hobby. Hobby professionals, you will have a chance to meet and mingle with professionals in the hobby like Eric Borneman and Anthony Calfo. A chance to be at a conference with hundreds of other people just as obsessed with aquariums as you are.

We have selected the Westin Peachtree Plaza as the host hotel for this event. It is the tallest hotel in the western hemisphere. Our negotiated room rate is $119.00 per night with discounted parking. Everyone that stays in the hotel will be given free internet access from their rooms.

This 73-story tower, topped by the revolving Sun Dial Restaurant, Bar & View, graces the heart of Atlanta. Connected to AmericasMart, The Westin Peachtree Plaza, is steps from CNN, Georgia Aquarium, Georgia World Congress Center and the Georgia Dome.

Contact Information:

MACNA XX
1266 West Paces Ferry Rd.
Suite 194
Atlanta, GA 30327
PHONE:
FAX: 860.540.2351
E-mail: info@macnaxx.com
Contact Form

PRODUCT REVIEW

Lighting for Reef Aquaria: Tips on Taking Light Measurements

By Dana Riddle

Hobbyists using a light-measuring device for the first time will probably be surprised at how rapidly the light field can change within an aquarium.

Published February 2008, Advanced Aquarist's Online Magazine.

Keywords (AdvancedAquarist.com Search Enabled): Dana Riddle, Light Meter, Lighting, Product Review, Quantum Meter, Sunlight, UV
Link to original article: http://www.advancedaquarist.com/2008/2/review

Proper lighting is one of several critical parameters in successful reef keeping. If there is not enough light, photosynthetic creatures will slowly perish. On the other hand, many corals (or, more correctly, their symbiotic algae called zooxanthellae) can not tolerate conditions of 'high' light and might not thrive. Excessive light is potentially harmful to symbiotic invertebrates but is also wasteful and needlessly expensive. Many hobbyists and clubs have recognized this and have purchased light-measuring devices and many more are considering a purchase. This article will explain the differences between several of the commonly available 'light' meters and will also examine the pros and cons of each.

Many of the tips listed below are applicable to any sort of light meter.

Lux Meters

'Lux' is an internationally accepted measure of light intensity. Lux meters do not 'see' blue and red light very well, and it is these wavelengths that are most responsible for promoting photosynthesis. They are designed to report light intensity to which the human eye is most sensitive (green light). Maximum lux is about 120,000 (in the tropics at noon on a cloudless day (many lux meters will report lux up to 50,000, making them adequate for many reef aquaria, but unsuitable for brightly lighted tanks and outdoor work).

Many use lux meters for measuring light and although these are better than not taking measurements at all, the preferred method is using a quantum meter (although see **'Converting Lux to PAR'** section later in this article). Lux meters are generally less expensive than PAR meters.

Quantum 'Light' Meters

Quantum meters or PAR meters (PAR is an acronym for Photosynthetically Active Radiation) are rather specialized light meters. PAR meters are the preferred method of measuring light within any aquarium containing things that photosynthesize whether they are corals, anemones, freshwater plants, etc. This is because the PAR meter can sense and report light ('photons' or 'quanta') that is responsible for promoting photosynthesis. Technically, this is described as those light wavelengths that are between 400 nanometers (nm) and 700nm. PAR, or Photosynthetic Photon Flux Density (PPFD) is reported in units of 'micro-Einsteins per square meter per second' ($\mu E \cdot m^2 \cdot sec$) or 'micro-Mol per square meter per second ($\mu Mol \cdot m^2 \cdot sec$). Either term is acceptable, and they are equivalent to each other (i.e., 1 $\mu E \cdot m^2 \cdot sec = \mu Mol \cdot m^2 \cdot sec$); however, $\mu Mol \cdot m^2 \cdot sec$ seems to have gained wider acceptance over the last few years.

Maximum PAR value (in the tropics at noon on a cloudless day) is 2,000 - 2,200 $\mu Mol \cdot m^2 \cdot sec$).

Quantum meters were once very expensive, with the most inexpensive units selling for ~$1,200. This is no longer the case, with decent meters selling for under $300.

There are a couple of quantum meters I can recommend. A 'laboratory grade' quantum meter (model LI-250A equipped with an underwater cosine-corrected sensor - LI-192) is built by Li-Cor (Lincoln, Nebraska). The meter (weather-proof but not submersible) and underwater sensor are rugged and will stand up to harsh conditions in the field. The meter can be calibrated for 'air' or 'water' readings (due to an optical property called the 'immersion effect'). There are some drawbacks - the meter and sensor combination is relatively expensive (>$1,100). The sensor itself (the body is made of brass) is large and does not lend itself to work in smaller aquaria. Li-Cor also offers a second sensor option for underwater light measurements - the spherical LI-193. Its appearance is similar to that of a light bulb, and this sensor can collect light from all angles. This sensor would be the best choice for those wanting to measure light intensity in micro-algae cultures.

It is truly a world-class instrument and is used by coral researchers around the globe and the best bet for those with exacting needs and/or really large aquaria. The spectral or quantum response is excellent.

Li-Cor also offers a datalogger capable of storing months of information (model LI-1400), but it is difficult to imagine the usefulness of this instrument to the majority of hobbyists. Note that all Li-Cor meters are capable of measuring very high PAR

intensity - 20,000 μMol·m²·sec (almost a magnitude greater than the most intense sunlight!).

Perhaps the best alternative is the quantum meter made by Apogee Instruments (Logan, Utah). The sensor is submersible (the meter itself is not!) and comes with a standard cable measuring about 6 feet in length. Custom cord lengths are available at additional cost. The Apogee's price is well below that of the Li-Cor meter, making it attractive to advanced hobbyists (clubs may want to consider its purchase, thus making it available to many).

The Apogee meter's construction is not as stout as that of the Li-Cor, but its cosine-corrected sensor is small and made of relatively inert anodized aluminum and plastic. The Apogee meter is limited in its measurement range - it reports PAR intensity up to 1,999 μMol·m²·sec, and the sensor's spectral response is not as good as that of the Li-Cor sensor. However, its measurements compare favorably with that of the Li-Cor meter and are accurate enough for the sort of measurements we'll make in aquaria. In short, the Apogee meter will likely be the meter of choice for most. All Apogee meter/sensor combinations retail for less than $300.

How to Take Measurements

A quality sensor will be 'cosine-corrected', meaning that it can effectively collect light from low angles with good efficiency. However, this does not mean that the sensor should be held in a position other than straight up. A sensor held in the vertical position will help ensure that accurate measurements are made.

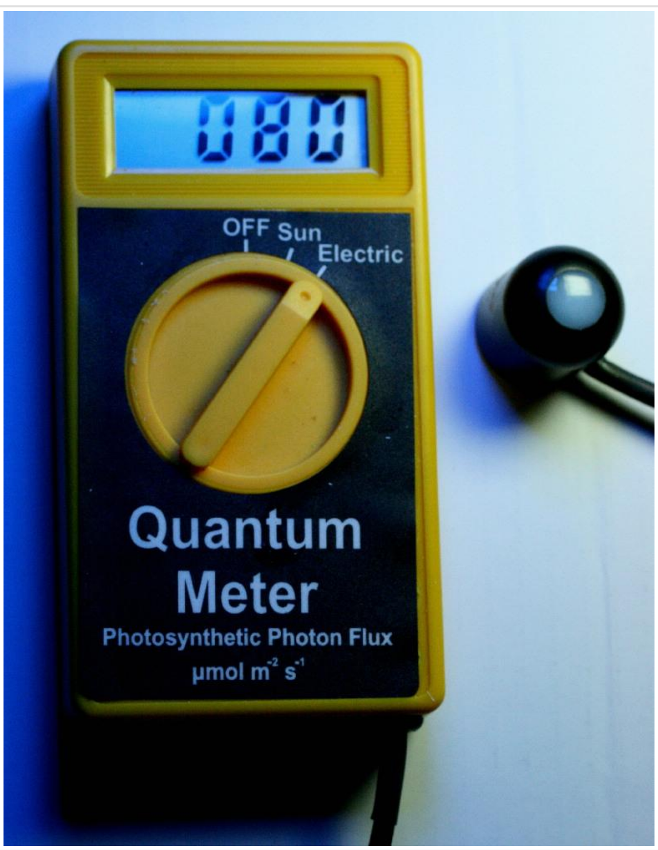


Figure 1. A relatively inexpensive PAR meter.

How to Make a Sensor Holder

Making a holder for your PAR sensor has several advantages. As most hobbyists know, it is best to avoid putting your hands in the aquarium - some corals don't like it, and some corals don't like you! It allows putting the sensor into spots too small for a hand and also allows better visuals on sensor positioning.

A holder for your sensor does not need to be elaborate. Over the years, my holders have evolved and become simpler and easier to transport and use. It is also very inexpensive (<$10) to make (See Figure 2 for a photo of the completed assembly).

Here's the parts list:

- 1 - Length of ½" CPVC pipe (usually sold in lengths of 10 feet)
- 2 - 1" diameter ceramic magnets
- 2 - ½" CPVC 90° elbows (a fitting called a 'wing 90' offers more surface area, and is shown in Figure 2)
- 1 - fine-point Sharpie pen
- SuperGlue (for permanent attachment) or aquarium-safe silicone cement (allows for future removal, if necessary).

Although a bolt can be used to attach the sensor to a 'leveling plate', it is less expensive and more convenient to use magnets as

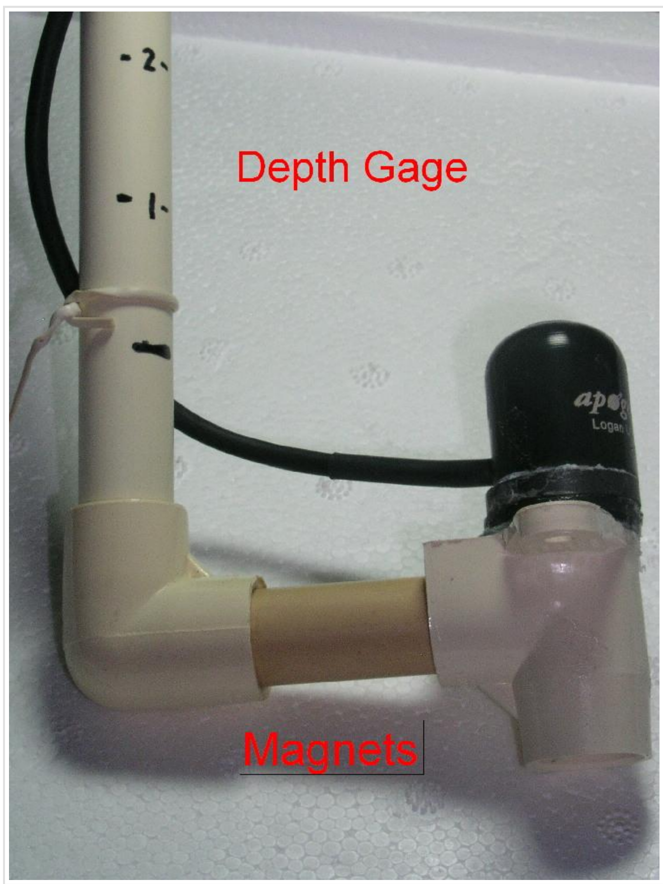


Figure 2. An inexpensive and easily constructed sensor holder.

a holdfast to the measuring rod. Use your choice of glue to attach a magnet to the 90° fitting. Also glue a magnet to the bottom of the sensor.

Once assembled, mark the rod in increments of 1 inch from the bottom up with the Sharpie or other indelible pen. This will serve as your depth gage.

Bear in mind that couplings are available to allow unusually long measuring rods to be 'broken down' for easy transport.

Effects of Temperature

Temperature will *usually* have an insignificant effect on PAR readings. Sensors are generally calibrated at a given temperature (20 °C, or 68 °F) and temperature below this point will cause a very small (~0.1% per °C) 'low' reading. In the same vein, 'warm' temperatures will cause 'high' readings. Operating temperature of the meter/sensor combination is limited by the sensor's temperature tolerance (usually up to 55°C, or 131°F).

Sensor Cleaning

Any fouling on the sensor lens could cause inaccurate measurements, so, obviously, the lens should be kept clean. We usually pride ourselves on our water quality management skills, but aquaria without overflows (such as sumps and refugia) may have a nearly invisible oily surface film that can coat and build up on the lens.

Use only a mild detergent and water along with an 'optical' quality paper for cleaning. Vinegar can be used to dissolve 'hard water' deposits. Blot the sensor dry in order to avoid 'fogging' or scratching the lens. Avoid petroleum or other 'strong' solvents and abrasive cleaners - these can damage the sensor's lens and ruin it!

Re-calibration

PAR meters and their sensors should be routinely re-calibrated. Apogee and Li-Cor recommend recalibration every 2 years. This is done at the factory for a nominal fee.

Converting Lux to PAR

If you have a lux meter, it is possible to convert lux to PAR. Since spectral quality plays a part in these conversions, each light source (actinic lamp, 6,500K metal halide, etc.) will have a difference factor. The equation is:

Lux ÷ Constant = µmol·m2·sec

Coral Light Requirements

Although we generally think of corals as originating from brightly lighted natural reefs and naturally assume corals need lots of light, the truth is that most corals require relatively little in order to thrive. For example, the 'Fox' coral (*Nemezophyllia* sp.) does quite well in low light. Thriving specimens have been noted in as little light as 35 µMol·m²·sec! On the other hand, an *Acropora* specimen (commonly called the 'Purple Monster') displayed magnificent coloration in the highest light intensity I have ever measured in an aquarium - almost 900 µMol·m²·sec (later research reveal that this coral photo-saturates at 300-400 µMol·m²·sec. I was wasting a lot of light and money!). Most corals will grow quite well in light intensities of 200-300 µMol·m²·sec.

Lux to PAR Conversion Factors

Light Source	Constant
Sunlight	54
Warm White Fluorescent	76
Cool White Fluorescent	74
URI (now *UV*) Actinic Fluorescent	18
URI (now *UV*) Daylight Fluorescent	54
Actinic/Daylight Combination	38
Philips 03 Actinic Fluorescent	40
Panasonic 6,700°K Power Compact	72
Panasonic 7,100°K / 6,700°K Combination	55
Osram Powerstar Metal Halide	57
Ushio 10,000°K Metal Halide	54
Coralife 10,000°K Metal Halide	30
Venture "Daylight" Metal Halide	46
Radium "Blue" Metal Halide	51
Fusion Sulfur Lamp	41
Westron Mercury Vapor Lamp	70
Iwasaki 6,500°K Metal Halide	57

Contact Information

See these sites for further information:

- www.apogeelighting.com
- www.licor.com

Have questions? Have PAR/lux data you'd like to share? Contact me at RiddleLabs@aol.com, and I'll get a response to you as soon as possible.

In Closing

Hobbyists using a light-measuring device for the first time will probably be surprised at how rapidly the light field can change within an aquarium (especially when using a point-source lamp such as metal halides. Stay cool - this is normal!). And it will become apparent that aquaria are not so bright (when compared to 'outdoor' measurements), and our rooms are actually very dimly lighted!

Post Script

The Marine Aquarium Conference of North America will be hosted by the Atlanta Reef Club in September 2008. You're missing out if you don't attend! See www.masna.org for details.

HOT TIPS

How do you choose a LFS?

By Advanced Aquarist's Readers

This month, our readers give tips on choosing a reputable local fish store.

Published February 2008, Advanced Aquarist's Online Magazine.

Keywords (AdvancedAquarist.com Search Enabled): Beginner, Hot Tips, Novice, LFS
Link to original article: http://www.advancedaquarist.com/2008/2/tips

A selection of useful tidbits of information and tricks for the marine aquarist submitted by Advanced Aquarist's readership. Readers are encouraged to post them to our Hot Tips sticky in the Reefs.org General Reefkeeping Discussion forum or send their tips to terry@advancedaquarist.com for possible publication. This month's Hot Tip theme is "Best Innovations in 2007 and 2008?" Please head over to our discussion forum and post your thoughts!

How do you choose a LFS?

Clean tanks with no algae on sand/glass.

Submitted by DaFrog

Friendly and knowledgeable staff, good livestock selection and healthy fish/corals/inverts. Sometimes with fluctuating livestock numbers, algal blooms are inevitable, so that's not too big of a concern to me. I do pay attention to livestock health though.

I actually work at a LFS. Our livestock, for the most part is healthy. But the store is new (about 6 weeks old) and algae/diatoms/etc come and go here and there due to having an immature system. But I know the livestock is healthy. So again, algae is not a big deal to me.

Submitted by camaroracer214

Ideally, I'd pick my LFS based on healthy specimens, good selection, good prices, and personable staff. Pragmatically, distance from where I live/work matters a lot.

Submitted by Len

I also like a store that has friendly, available, and helpful staffers. I like a place that has good selection of healthy fish, and is reasonably priced. If there are two stores with equal livestock and aesthetics, I'd shop at the one with the more available staff - even if it cost me a couple more dollars. I can't stand waiting an hour for somebody to bag my purchase. But if the store's tanks look like garbage, I'm not staying around to see prices and what the staff is like.

Submitted by Magilla Gorilla

I think friendly and knowledgeable staff are the most important first impressions. Overall tank care and maintenance as the others noted are also critical. Livestock health and the appropriateness of the setting are very telling of the store's experience and how they run their business. e.g. are high-light needs corals under the appropriate lighting? obvious parasites visible? are the fish healthy? do they quarantine? etc.

A big plus for me is if a store will hold a livestock after purchase for pickup later. this tells me they're confident in their own abilities and that they're also confident that the livestock in question is healthy.

Submitted by tinyreef

ONLINE NEWS

Reefs in the News

From Online News Sources

Media coverage of the state of our world's reefs, interesting information, and other marine-related news.

Published February 2008, Advanced Aquarist's Online Magazine.

Link to original article: http://www.advancedaquarist.com/marinenews

High-tech maps reveal Puerto Rico's coral reefs (MSNBC)

Yahoo! Coral Reefs News
February 29, 2008 05:26 PM

In Puerto Rican waters, shallow-water reefs have been harmed by pollution and overfishing. Nearly half of the coral in areas of the neighboring U.S. Virgin Islands died from diseases after months of warming waters in 2005.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=119epfajm/*http%3A//www.msnbc.msn.com/id/23407930/

Specialized Surface Wind Instruments Fly Onboard Nationâ€™s Hurricane Hunter Fleet

NOAA News Releases
February 29, 2008 04:21 PM

For the first time, Americaâ€™s entire fleet of aircraft that fly through hurricanes now have instruments that measure surface winds, giving forecasters at NOAAâ€™s National Hurricane Center a better view of the intensity and the size of these powerful storm systems.

Read More...

Source:
http://www.noaanews.noaa.gov/stories2008/20080229_hurricane.html

Officials to discuss coral proection in the Keys (7 News Miami)

Yahoo! Coral Reefs News
February 29, 2008 12:59 PM

KEY WEST, Fla. -- Florida Keys commercial fishing and conservation groups say they want coral reef protection policies that focus on pollution and climate change issues.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11tobb307/*http%3A//www.wsvn.com/rss/read/news/articles/local/MI78444/

San Mateo Daily Journal (San Mateo Daily Journal)

Yahoo! Coral Reefs News
February 29, 2008 08:55 AM

Coral, parrotfish and sharks filled first-grade teacher Denise Deghiâ€™s days this week, experiences she shared with San Mateo Park Math and Science Magnet School via teleconference yesterday.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11uukihn2/*http%3A//www.smdailyjournal.com/article_preview.php?id=88101

NOAA Helps Natâ€™l Coral Reef Institute to Grow Coral in Laboratory to Restore Damaged Reefs

NOAA News Releases
February 28, 2008 10:21 PM

Scientists at the National Coral Reef Institute are currently growing more than 400 corals from the larval stage as part of NOAA-funded research, and will transplant them to restore damaged coral reefs. "NOAA strongly supports research that will help managers develop new tools to address coral restoration," said retired Navy Vice Adm. Conrad C. Lautenbacher, Ph.D., under secretary of commerce for oceans and atmosphere and NOAA administrator. "In this Year of the Reef, such innovative approaches may provide a new way forward to protecting these valuable resources."

Read More...

Source:
http://www.noaanews.noaa.gov/stories2008/20080228_coral.html

Animal Lovers Should Admire Hawaii's Sea Mammals From a Distance (KHNL News 8 Honolulu)

National Marine Sanctuary in the News
February 28, 2008 09:48 PM

(KHNL) -- Endangered mammals share our ocean with us. But our curiousity may soon lead to their extinction. Federal agencies acknowledge the major issue used to surround boaters and swimmers getting too close to humpback whales during the migration season.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11ioqhn5t/*http%3A//www.khnl.com/Global/story.asp?S=7941597

From Sharks To Microbes, Key Data At Central Pacific's Line Islands Archipelago Captured

ScienceDaily: Coral Reef News
February 28, 2008 10:00 AM

An ambitious expedition to a chain of little-known islands in the central Pacific Ocean has yielded an unprecedented wealth of information about coral reefs and threats from human activities. The exploration of four atolls in the Line Islands, part of a chain approximately a thousand miles south of Hawaii, has produced the first study of coral reefs comprehensively spanning organisms from microbes to sharks.

Read More...

Source:
http://www.sciencedaily.com/releases/2008/02/080225213657.htm

Total magnet status (Odessa American)

Yahoo! Coral Reefs News
February 27, 2008 11:56 PM

Hays Magnet Academy fourth-grader Itzzel Orona said her magnet class takes her places â€" from the Alamo to Australia. Recently in her class, the 10-year-old worked on building a coral reef for an exercise on Australia.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=129nme01k/*http%3A//www.oaoa.com/news/school_14354___article.html/hays_magnet.html

Innovative Technology to Bring NOAA Monterey Bay National Marine Sanctuary to Classrooms Nationwide Mar. 2-7

NOAA News Releases
February 27, 2008 09:04 PM

NOAA's National Marine Sanctuary Program will use innovative Internet and satellite technology to transport students across the country to a scientific expedition in Monterey Bay National Marine Sanctuary. The experience, which will feature the use of broadcasts from autonomous underwater vehicles, will be accessible on the Internet and telecast to a network of partner Boys and Girls Clubs across the nation via satellite from Mar. 2â€"7.

Read More...

Source:
http://www.noaanews.noaa.gov/stories2008/20080227_monterey.html

Blue Whale Death Investigators Point Finger (Santa Barbara Independent)

National Marine Sanctuary in the News
February 27, 2008 07:14 PM

Natural History Museum necropsies slide show proves ship-strike injuries; scientists laud shippers for slowing to save Blue Whales.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=12ssm1bhc/*http%3A//www.independent.com/news/2008/feb/27/blue-whale-death-investigators-point-finger/

Yacht stuck for 2 Â½ years finally free (Miami Herald)

National Marine Sanctuary in the News
February 27, 2008 08:28 AM

When the winds of Hurricane Wilma blew across Key West in 2005, they dragged a $16 million, 158-foot luxury yacht called the Legacy into shallow tidal flats.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11ts3dnma/*http%3A//www.miamiherald.com/news/florida/story/434959.html

Yacht stuck for 2 Â½ years finally free (Miami Herald)

National Marine Sanctuary in the News
February 27, 2008 08:22 AM

When the winds of Hurricane Wilma blew across Key West in 2005, they dragged a $16 million, 158-foot luxury yacht called the Legacy into shallow tidal flats.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=122admmaj/*http%3A//www.miamiherald.com/news/florida_keys/story/434959.html

NOAAâ€™s FishWatch Provides Facts on Safe, Sustainable Seafood

NOAA Government News Releases
February 26, 2008 02:36 PM

FishWatch.noaa.gov, NOAAâ€™s new consumer education Web tool, offers valuable information on seafood availability, safety, quality, storage, preparation, and health guidelines.

Read More...

Source:
http://www.noaanews.noaa.gov/stories2008/20080225_fishwatch.html

Scripps expedition provides new baseline for coral reef conservation (PhysOrg)

Yahoo! Coral Reefs News
February 26, 2008 12:10 PM

An ambitious expedition led by scientists at Scripps Institution of Oceanography at UC San Diego to a chain of little-known islands in the central Pacific Ocean has yielded an unprecedented wealth of information about coral reefs and threats from human activities.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11dkimog5/*http%3A//www.physorg.com/news123229847.html

NOAA Chooses Bonaire As Most Unspoiled Coral Reef Environment (PRWeb)

Yahoo! Coral Reefs News
February 26, 2008 08:19 AM

The reef off the coast of Bonaire has always been a popular scuba and snorkeling spot. This month, the National Oceanic and Atmospheric Administration (NOAA) designated Bonaire as having the most pristine coral reef environment. (PRWeb Feb 26, 2008) Read the full story at http://www.prweb.com/releases/2008/02/prweb720514.htm

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11p9rrul5/*http%3A//www.prweb.com/releases/2008/02/prweb720514.htm

Artificial coral reefs to improve fish population in TN (Deccan Herald)

Yahoo! Coral Reefs News
February 26, 2008 06:49 AM

Dr Mohammed Kasim, Principal Scientist at CMRI, said the project was taken up nine months ago as too much fishing activity, coupled with environmental degradation and change in climate, affected delicate fish resources in inshore waters.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12v48aq7l/*http%3A//www.deccanherald.com/Content/Feb262008/scroll2008022654281.asp?section=scrollingnews

Scripps Expedition Provides New Baseline for Coral Reef Conservation (Newswise)

Yahoo! Coral Reefs News
February 26, 2008 01:32 AM

From sharks to microbes, scientists capture key data at the central Pacific's Line Islands archipelago. An ambitious expedition led by scientists at Scripps Institution of Oceanography at UC San Diego to a chain of little-known islands in the central Pacific Ocean has yielded an unprecedented wealth of information about coral reefs and threats from human activities.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11pp2r818/*http%3A//www.newswise.com/articles/view/538024/?sc=rssn

Butterfly Fish 'May Face Extinction'

ScienceDaily: Coral Reef News
February 25, 2008 10:00 PM

A beautiful black, white and yellow butterflyfish, much admired by eco-tourists, divers and aquarium keepers alike, may be at risk of extinction, scientists have warned. The case of the chevroned butterfly fish is a stark example of how human pressure on the world's coral reefs is confronting certain species with 'blind alleys' from which they may be unable to escape, says one of the scientists.

Read More...

Source:
http://www.sciencedaily.com/releases/2008/02/080225072629.htm

Volunteers Count Whales in NOAAâ€™s Hawaiian Islands Humpback Whale National Marine Sanctuary

NOAA News Releases
February 25, 2008 04:38 PM

More than 700 volunteers gathered data from the shores of Oahu, Kauai, the Big Island, and Kahoolawe for Saturdayâ€™s annual Hawaiian Islands Humpback Whale National Marine Sanctuary Ocean Count.

Read More...

Source:
http://www.noaanews.noaa.gov/stories2008/20080225_humpback.html

Qatar plants artificial coral reef (AME Info)

Yahoo! Coral Reefs News
February 25, 2008 05:51 AM

To protect the ecosystem, Qatar University's Environmental Studies Center and Qatar Petroleum initiated a project which implants artificial coral reef, cited The Peninsula. The method is believed to encourage the growth of coral reefs and ultimately enhance their ecosystem.

Read More...

Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=116i4b775/*http%3A//www.ameinfo.com/147945.html

Artificial coral reef project to protect marine environment (The Peninsula)

Yahoo! Coral Reefs News
February 25, 2008 01:45 AM

DOHA â€¢ Qatar University's Environmental Studies Center (ESC), in collaboration with Qatar Petroleum (QP), has initiated the project for the introduction of artificial coral reef, a method which is fast becoming approved internationally to encourage the growth of coral reefs and ultimately enhance their ecosystem.

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Perfect weather yields high whale counts (The Garden Island)

National Marine Sanctuary in the News
February 24, 2008 02:14 PM

AHUKINI â€" By the time Meph Wyeth signed on, the Crater Hill observation site was filled so she opted to watch for whales at Ahukini yesterday during the February Ocean Count.

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Caribbean coral reefs in danger of extinction (Trinidad Express)

Yahoo! Coral Reefs News
February 24, 2008 03:26 AM

SERENE: Tourists take a plunge into the blue to look at the coral reef in Tobago. -Photo: JERMAINE CRUICKSHANK England's Prince Charles-who has become a global 'knight' of the environment-will spend part of his upcoming visit to T&T with the Buccoo Reef Trust in Tobago.

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Promoting coral reef conservation (The New Straits Times)

Yahoo! Coral Reefs News
February 24, 2008 12:06 AM

PETALING JAYA: Once described by famed oceanographer Jacques Cousteau as a piece of art, Malaysia's islands owe much of their splendour to the coral reefs that surround them.

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Ocean acidification threatens underwater ecosystems (Times Online)

Yahoo! Coral Reefs News
February 23, 2008 06:45 PM

Scientists studying Australiaâ€™s Great Barrier Reef may have detected the first signs of impact of ocean acidification after finding a sharp cut in growth rates in some corals.

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Biologist combs Bay Area beaches for remains (The Argus)

National Marine Sanctuary in the News
February 23, 2008 10:53 AM

The first time Ray Bandar cut off a dead animal's head, it was in the name of art. It was in 1953, and Bandar was 26 when he spotted the remains of a "stinky, bloated" harbor seal on Ocean Beach that everyone else was trying to avoid.

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Reef Nutrition Marine Live Feeds are produced by Reed Mariculture, the world's largest producer of marine microalgae concentrates. We supply algal feeds and zooplankton to universities, marine ornamental growers, and over 500 fish, shrimp, and shellfish hatcheries in 70+ countries around the world.

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Southern California Caulerpa Action Team

An important goal of the Southern California Caulerpa Action Team is the detection of undiscovered infestations of C. taxifolia or other invasive species of Caulerpa, and the prevention of their spread.

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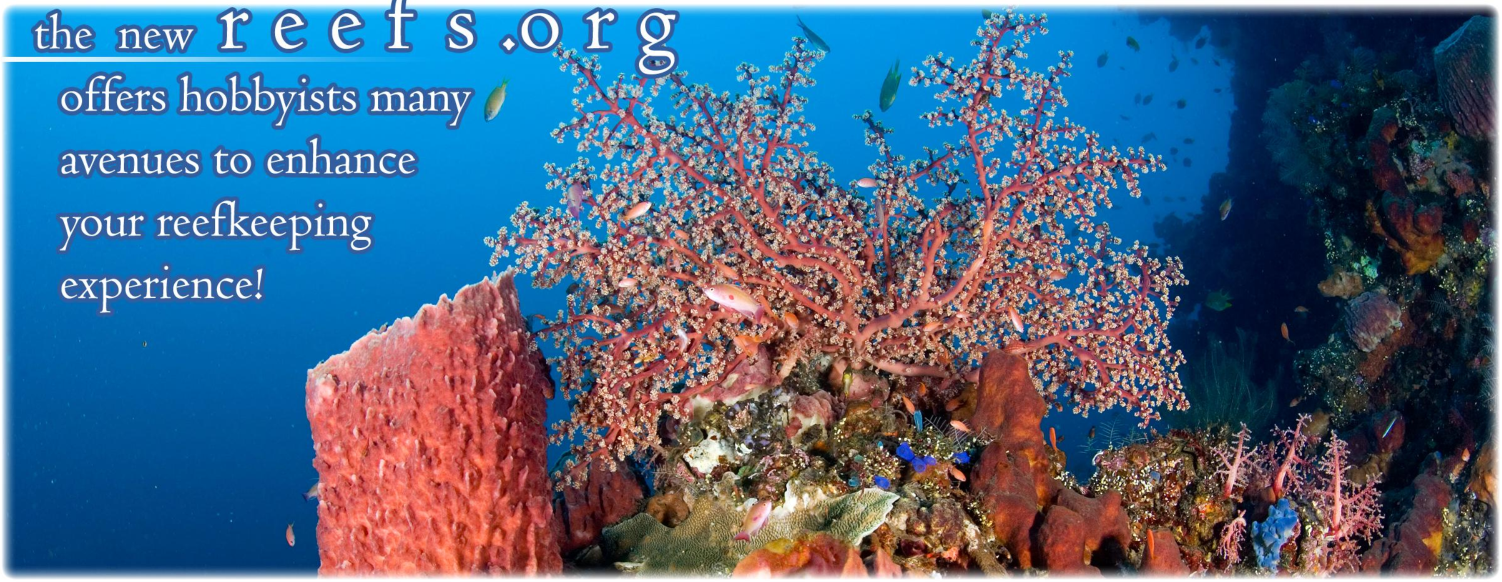
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